A STUDY OF SATELLITE REGENERATIVE REPEATER FOR MILITARY COMMUNICATION

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SQN. LDR. K. O. OOMMEN

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CERTIFICATE

This is to certify that the thesis entitled 'A STUDY OF SATELLITE REGENERATIVE REPEATER FOR MILITARY COMMUNICATION' by SQN. LDR. K.O. OOMMEN has been carried out under my supervision and that this has not been submitted elsewhere for a degree.

Vishwanath Sinha

August, 1979

(V. Sinha)
Assistant Professor
Department of Electrical Engineering
Indian Institute of Technology
K A N P U R.

ABSTRACT

The present communication satellites are frequency ranslating types. But with the improvement in electronic ardware technology and availability of launch vechicles apable of putting more payload into orbit, it is now ossible to launch more complex satellites. It is then advanageous to introduce regeneration on-board the satellite.

In this thesis after introducing various types of accesses, two types of accessing techniques namely, Time Division Multiple access and Spread Spectrum multiple access are briefly explained, as these techniques are more compatible with military requirements. Computer simulation (on DEC-1090 system) of TDMA and SSMA with carrier modulations of BPSK, DPSK and QPSK have been carried out and performances of the systems are reported. In SSMA simulation processing gains of 10,13 and 16 dB have been used.

On-board regeneration with various types of accesses is studied, with a view to select a suitable system for military purposes. SSMA uplink and TDMA downlink comes out to be most suitable and power budget calculations for this system are also studied and suitable recommendations for future work in this field are given.

ACKNOWLEDGEMENT

I am extremely grateful and indebted to Dr. V. Sinha for his able guidance, valuable suggestions and creative criticism throughout this work.

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CHAPTER 1

INTRODUCTION

The present communication satellite repeaters are simply frequency translating types, i.e. translating in frequency the signals received on the uplink to that to be transmitted on the downlink. This has been so due to the launch vehicle limitations and requirement for high reliability. But with the progress of technology, the constraints on size, weight and complexity of the repeater payload have been relaxed. Launch vechicles capable of placing very high payloads into synchronous orbits are now available. Further microelectronic circuits considerably reduce the size and weight of a circuit to perform a given function. Also the reliability of the components in space enviornment is now well proven. Thus the technology necessary to build, launch and operate complex communication satellites is or will soon be available. In this context, it may be worthwhile to transfer the task of providing some desired communication processing to the satellite segment for the added gain of better communication facilities. The processing on board may be baseband regeneration, modulation conversion, error control techniques, switching and rerouting, interference removal etc.

1.1 Statement of the Problem

Normally in terrestrial communication links, regnerative repetiti n is considered worthwhile only if the number of repeating stages is large. In satellite communication, though the repeating stage is only one, repetitive regeneration can be resorted to due to **its** various advantages [1] some of which are listed below.

i) Because of regeneration on board the satellite various kinds of signal processing can be employed, e.g. since downlink is power limited error correcting technique can be resorted to for downlink. Signal processing on board will provide new conveniences to the users and efficient use of the communication capacity.

ii) With regeneration to achieve a certain total carrier to noise plus interference power ratio [C/(N+I)], the uplink and downlink C/(N+I) is much less than in the case of non-regeneration, e.g. with regenerative repeater, in PSK/TDMA to achieve a total C/(N+I) of 15 dB, uplink C/(N+I) of 18 dB and downlink C/(N+I) of 17.5 dB are required. Whereas in non-regenerative system the uplink C/(N+I) of 24 dB and downlink C/(N+1) of 20.5 dB are required to achieve the same total C/(N+I). Thus with regeneration 6 dB on the uplink and 3 dB on the downlink can be saved.

iii) Modulation format can be rearranged for the downlink transmission thus making the ground receivers simpler, which may be required say for military communication purposes.

iv) Cochannel interference will become predominant interference in future communication satellite systems because of frequency reuse by multiple spot beams and increase of the number of satellites in a given orbital arc. This interference also can be removed by regeneration.

v) Removal of uplink intentional interference and thermal noise results in saving of downlink power, since downlink power is not wasted in transmitting unwanted interference and downlink power is a premium factor in satellite communication.

vi) Since uplink and downlink can be isolated uplink interference and thermal noise can be removed.

1.2 Review of Communication Satellite Systems

The idea of geostationary satellite was first proposed by Arthur. C. Clarke after the second world war in an article in Wireless orld entitled 'Extraterrestrial Relays'. His proposal was for the use of FM voice broadcast. He also foresaw the use of solar cells.

1.2.1 Beginning of the satellite era

Moon reflections for communication purposes were demonstrated in the late forties and early fifties. This type of communication which existed till 1962 was limited by the

'availability' of the moon at the transmitting and receiving stations. Then started the period of passive satellites with the 'ECHO' balloon in 1960. These passive satellites were handicapped by the inefficient use of transmitter power.

But with the advent of space electronics, the passive systems were replaced by active satellites. Score was the first active satellite which was launched in December 1958. Apart from early space probes like Sputnik, Explorer, and Vanguard, as well as the score and Courier projects, which were early communication satellites, the major experimental steps in active communication satellite technology were the Telstar, Relay and Syncom projects.

Project Telstar was the first one capable of relaying TV programs across the Atlantic. The overall communication capability was 600 voice telephone channels, or one TV channel. The orbit used was such that the satellite was visible for short periods only. This project was developed by Bell Laboratories. Project Relay developed by RCA was a similar project. In 1964 the International Telecommunications Satellite Consortium, known as Intelsat was formed to design and maintain a global commercial communication satellite system.

1.2.2 Commercial development

The launch of Intelsat I (known as Early Bird) in April 1965 initiated a new era in telecommunications. Its capacity

was 240 voice circuits and interconnected Europe and USA. The Intelsat II in 1967, Intelsat III in 1968 provided coverage of both Pacific and Atlantic regions. The fully mature phase of satellite communication could be considered as having begun with Intelsat IV in 1971. Intelsat IV was augmented in the Atlantic region by the next series Intelsat IV-A in 1976. Nominal capacity of the Intelsat IV is 7500 voice channels and that of IV-A is 12,500 voice grade channels. The types of modulated signals carried by the Intelsat network include: data, facsimile, teletype, television (monochrome and colour) and voice.

There are 42 satellite communication systems today, which are in active operation or for which equipment is being built [1]. We will briefly review the features of some of the major satellite systems in use today, besides the highly successful Intelsat.

1.2.2.1 Applications Technology Satellite

Of the experimental satellite programs to date, perhaps the most encompassing has been NASA's Application Technology Satellite. The basic philosophy of the ATS program has been the development of multiple mission satellites having a large and adaptable volume for mounting the various experimental payloads. ATS missions 1 through 5 carried out experiments like SHF voice/television experiments at 6/4 GHz, VHF

communications experiments with mobile stations, experiments in the aeronautical and Maritime fields. ATS-6, last of ATS series was successfully launched in May 1974. 6 GHz and 4 GHz radio frequency interference between satellite and Terrestrial systems, 860 MHz Television Relay using small Terminals (TRUST) and Satellite Instructional Television Experiment (SITE), 2.5 GHz Educational Television Experiment, Health Education Telecommunication experiment were the experiments which were carried out by this satellite [2].

1.2.2.2 Communication technology satellite (CTS) program

In 1971 CTS program was established as a result of agreement between Canada and USA. The satellite was launched in 1975. Some of the telecommunications experiments proposed were :

i) TV Broadcast

ii) Educational TV (ETV) with a voice or data return channel for interactive programs

iii) TV remote transmission

iv) Radio Broadcast

v) Two way voice

vi) Digital data transmission

vii) Investigation of high speed data transmission by satellite

viii) Investigation of time division multiple access techniques

1.2.2.3 The Symphonie Project

In 1967 France and West Germany decided to cooperate in this project. The first symphonie was launched on December 1974. This is a geostationary type with circular orbit. Space Applications Centre, ISRO carried out 'Satellite Telecommunications Experiments Project' from June 77 to May 79 with this satellite. The experiments included remote TV origination/reception radio networking, SCPC, TV with multiple audio and PCM/PSK/FDMA'[3].

1.2.2.4 USSR Satellites

MOLNIYA is the USSR domestic satellite system. The satellite system is placed in a highly inclined elliptical orbit over USSR with a period of 12 hrs. To provide 24 hour coverage, two to three spacecraft are placed in a phased orbit. In March 1974 USSR launched its first geostatonary satellite known as STATSIONAR I.

1.2.2.5 TELESAT - the Canidian domestic system

The space segment consists of three spin-stabilized satellites in geostationary orbit. The first of the satellites known as ANIK was launched in November 1972. The system is capable of providing television, broadcast Radio, data and facsimile transmission services throughout Canada, and can handle both analog and digital signals.

1.2.2.6 INSAT - the Indian domestic satellite

This Indian National Satellite is to be launched by 1982. It will have 12 transponders each with a band width of 36 MHz. The satellite is supposed to provide the following facilities [4]

i) Village broadcast UHF TV

ii) Point-to-point voice frequency (VF) trunks

iii) TV network distribution

iv) Multiple-access communication for low-duty-cycle and remote users

1.2.2.7 Other systems

Besides these there are various other systems in operation or under design, civil and military like Comsat, RCA SATCOM, Westar, DSCS. The particulars of these are given in [1]. The systems available for Maritime satellite communications, Broadcast satellite service, Mobile service are described in [2].

1.2.2.8 Futuristic developments

The areas in which future developments in satellite communication will take place are Onboard regeneration and frequency reuse. Onboard regeneration is discussed later in this thesis. One practical way of increasing communication bandwidth is to reuse the frequency band by means of multiple spot beams or orthogonal polarization [5,6,7]. Another area

where development will take place is the use of higher frequencies for satellite communication [8,9,10].

1.3 Modulation and Multiple Access Techniques

A geostationary satellite which 'sees' approximately one third of the earth's surface can provide in principle communication between any two points within that region of the earth's surface. But how many users can simultaneously use this facility within the constraints of power and bandwidth is the problem of multiple access.

1.3.1 Basic modulation techniques

The efficiency of a satellite system depends upon the modulation technique used, which consists basically of two parts :

i) A method of assembling the individual channels before they are modulated onto the main carrier. i.e. frequency division multiplexing (FDM) or time-division multiplexing (TDM)

ii) A method of modulating the multiplexed baseband onto the RF carrier, i.e. frequency modulation (FM), phase modulation (PM), phase shift keying (PSK), etc.

Individual techniques may be combined to suit a particular situation and this gives rise to composite techniques such as FDM/FM, TDM/FM or TDM/PSK.

1.3.1.2 Multiple access techniques

In the early days of satellite communication only two stations could communicate with each other through a satellite at a time, but this was very inefficient. Hence means had to be found by which more stations could simultaneously gain access and use the satellite at the same time. This gave rise to the development of multiple accessing techniques. Basically multiple access can be divided into four categories :

i) Frequency division multiple access (FDMA)
ii) Time division multiple access (TDMA)
iii) Spread-spectrum multiple access (SSMA)
iv) Pulse address multiple access (PAMA)

1.3.1.3 Frequency division multiple access (FDMA)

The available transponder bandwidth is divided in FDMA into a number of non-overlapping frequency bands with bandwidths dependent upon the traffic of each carrier. In the present Intelsat systems the channel capacity has been standardized to 24,60,132 or 900 channels [7]. But there are disadvantages in this type of multiple accessing. The satellite repeater is a nonlinear device and creates signal impairments such as intermodulation and crosstalk. To reduce these effects the output amplifier has to be backed off to operate in the linear region, and therefore, the available EIRP of the satellite is reduced. Also guardbands between channels are necessary and

spacing of the carriers to allow for different capacities should be done carefully to reduce intermodulation distortion. These effects produce a reduction in satellite transponder capacity with increased number of accesses as shown in Fig. 1.1. For multiple carrier operation, the satellite power must be shared among all carriers and this requires close control of the uplink transmitter power. But the major disadvantage is that this system requires carriers to be allocated permanently to the various earth stations and thereby makes the system difficult to modify with changes in traffic distributions [11,12].

1.3.1.4 Time division multiple access (TDMA)

In TDMA the transponder is used exclusively by a single earth station during a specified time slot. At any one time, therefore, only one carrier is using the transponder output amplifier (which may be operated at saturation) and earth station power control is not necessary. Also here the capacity of the transponder does not reduce drastically with increased number of accesses as shown in Fig. 1.1 [13].

This system requires synchronization of the various station bursts.

1.3.1.5 Spread spectrum multiple access (SSMA)

The information bearing signal is spread in bandwidth

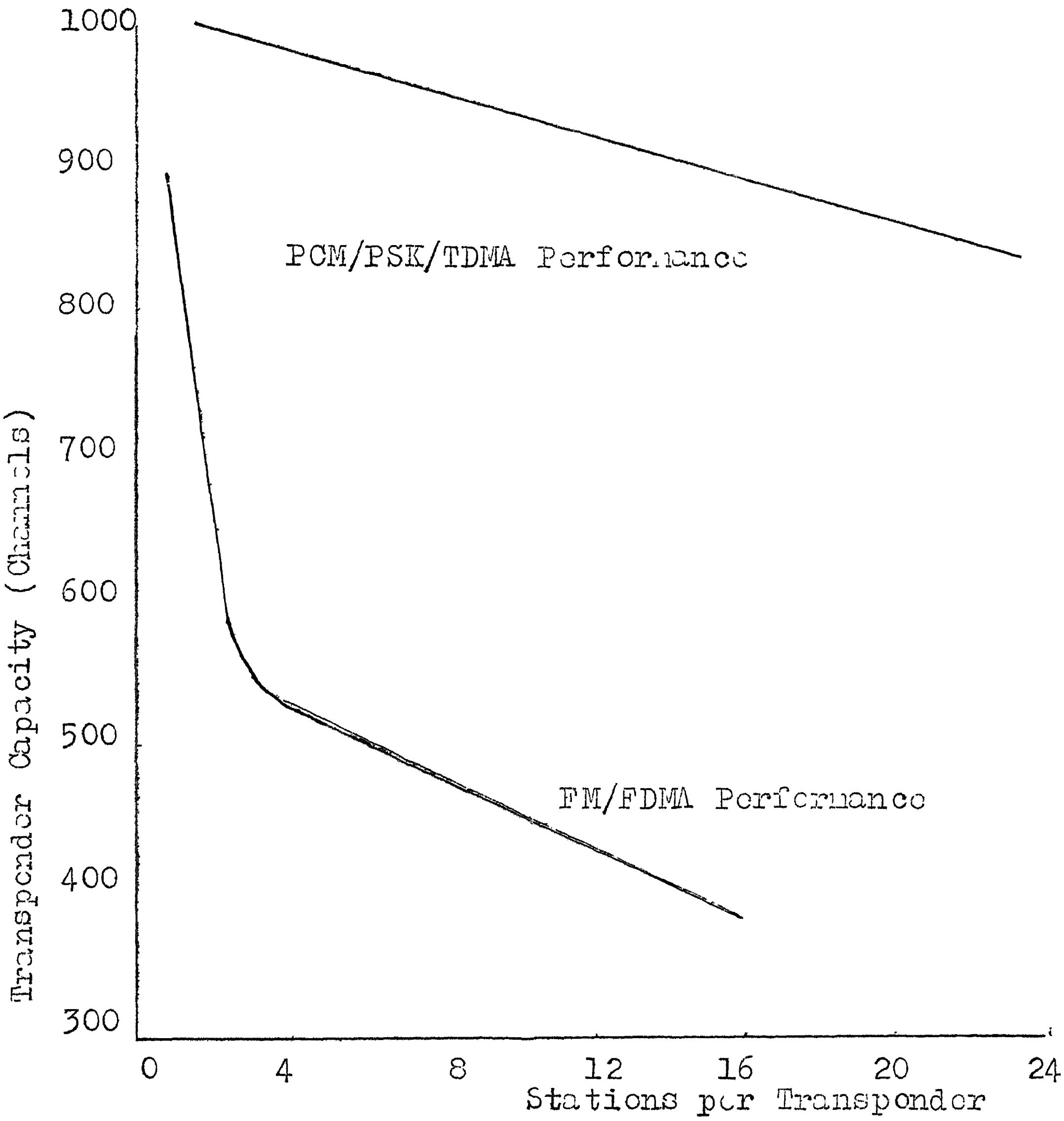


Fig. 1.1 Access Capability

with the help of a code. So at a particular time one user has continuous (but not exclusive) usage of the entire satellite bandwidth. One of the purposes of spreading the signal is to make it look like a white Gaussian noise [14]. This process inc the immunity of signals to interference. Recovery of the signal is done with the exact inverse operation with the same code stored at the receiver. Hence this technique requires code synchronization and complex terminal equipment.

1.3.1.6 Pulse address multiple access (PAMA)

PAMA is a method in which time-frequency pulse patterns are generated and used as addresses. The frequency spectrum is split into bands and pulses are transmitted in the various bands at preassigned times. Reception of signals is accomplished by detection of both frequency-and time-slot positions. Like SSMA, a large number of codes can be used and hence PAMA has random-access capability. But this has low energy efficiency [15].

1.4 Demand Assignment

Earth stations having continuous traffic over a given number of channels use preassigned channels. But channel economy can be achieved by using Demand Assignment. In demand assignment all channels are pooled and may be used by any station according to its instantaneous traffic load. Demand Assignment Communications may take various forms. If

both ends of all the channels are undedicated so that any station may use any channel it is known as 'fully variable'. But on the other hand if only one end is free then it is known as 'semi variable'. Intelsat SPADE is an example of demand assigned multiple access system [16].

1.5 Organization of the Thesis

In Chapter 2 of this thesis we will consider TDMA and SSMA in detail, Chapter 3 gives the various on board regeneration systems possible, Chapter 4 gives the simulation results and in Chapter 5 the power budget calculations for a typical link for military applications are presented. We conclude the thesis in Chapter 6 with suggestions for further work in this area.

CHAPTER 2

DIGITAL MULTIPLE ACCESSING TECHNIQUES

A satellite communication system to meet military needs have various constraints which differ from the normal requirements of other users. Message and transmission security, antijamming capabilities, flexibility of network configuration etc. are some of the requirements which differentiate the military satellite communication system. Time-division-multiple-access (TDMA) and Spread spectrum multiple access (SSMA) techniques are better suited for these requirements than Frequency division multiple access (FDMA). In this chapter we will briefly review TDMA and SSMA.

2.1 Time Division Multiple Access

Time division multiple access (TDMA) can be defined as the time sequenced entry at the satellite transponder of RF signals originating from different ground stations. Since efficient conversion of the potential satellite R.F. power output to achieve best possible information transmission capacity is important, it is necessary to select a modulation scheme to meet this requirement. Since buffer storage is necessary in TDMA, a digital modulation scheme is more compatible with TDMA. Fig. (2.1) shows the comparitive voice channel

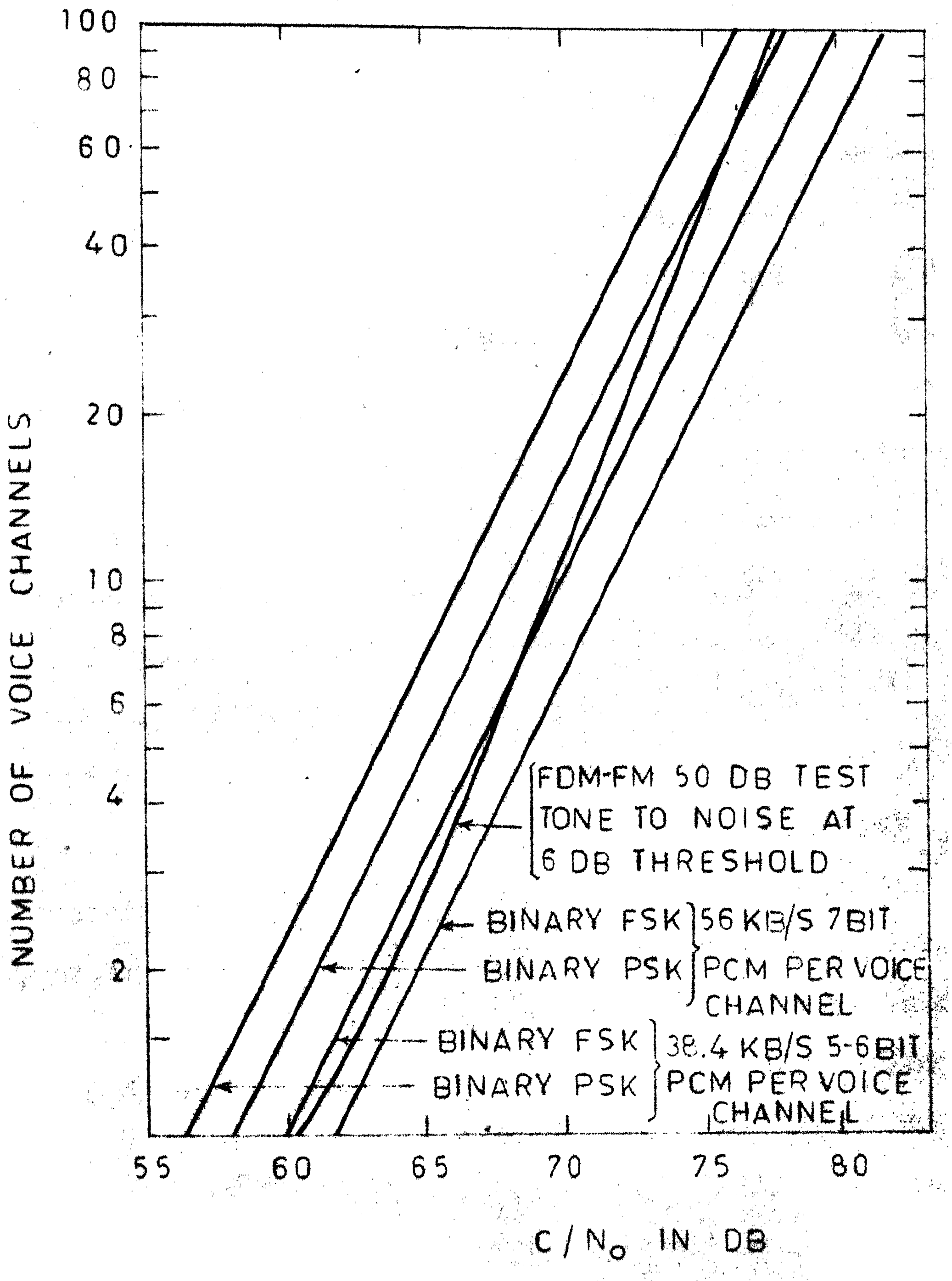


FIG.2.1 VOICE CHANNEL PERFORMANCE

performance of standard frequency division multiplexing/freq modulation (FDM/FM) with 4 KHz spacing and multiplexed PCM voice circuits with binary frequency shift keying (BFSK) or binary phase shift keying (BPSK) [17]. It is evident from this, that the digital forms of carrier modulation is more efficient than analog FDM/FM for the transmission of both analog voice and digital data traffic over the range of C/N_0 assumed. Added improvement in terms of bandwidth - power trade-off can be obtained by using M-ary modulation techniques. Further, constant envelope modulation scheme is preferred because satellite transponder in general has a non-linear amplitude transfer characteristic. Among these constant envelope modulation schemes, phase shift keying is preferred because of better bandwidth power trade-off considerations.

The primary considerations in TDMA are fast initial acquisition, suitable synchronization methods and arrangement of individual bursts in proper format which maintains high efficiency [18]. In TDMA the time axis is divided into frames, which in turn is divided into shorter slots which can be accessed by ground stations. The slots must contain a 'preamble' containing signals that perform the following functions.

i) If coherent modulation is employed, carrier phase must be extracted at the beginning of the framing signal and each burst

ii) Clock recovery must be done for efficient demodulation

iii) Unique word to indicate the burst start

iv) Station identification and status code (SIC)

v) Signalling channel

vi) Teletype orderwire channel

vii) Voice order-wire (VOW)

The normal frame structure is shown in Fig. 2.2. The first part is the frame sync of duration T_{FS} transmitted by a master station which serves to identify a particular point

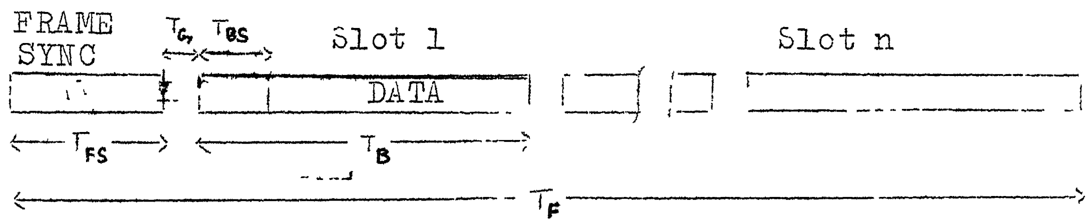


Fig. 2.2 TDMA Frame Structure

in time. This consists of signals for carrier recovery (if coherent demodulation is employed), bit synchronization and a unique word with good correlation properties to establish the bit position which is the start of the frame [19]. Following the frame sync are n bursts from n different stations, each of duration T_B. Each burst consists of a preamble of of duration T_{BS} followed by information bits.

The preamble of each burst can have three possible forms. For noncoherent modulation with a bit coherent frame T_{BS} is zero. For non-bit coherent frames, with either coherent or non-coherent RF modulation, the burst has the same form as frame sync. In bit-coherent system, the receiver clock is obtained from the frame sync. For this approach to be possible each burst must be positioned accurately so that the position error is small with respect to a symbol duration [17]. But as the frequency and phase of the clock cannot be assumed to be coherent from burst to burst within a frame at high data rates, the clock has to be recovered for each burst. This is non-bit coherent frame. Since the preamble does not contribute to the information carrying capacity of the frame it should be kept as small as possible to increase the frame efficiency which can be represented as

$$\eta = 1 - \frac{T_{FS} + (n+1)\ T_G + n\ T_{BS}}{T_F} \tag{2.1}$$

where T_G is the guard time between bursts. This is a non-transmit period and is inserted to prevent burst from actually overlapping each other.

An earth station that desires to enter a time-slot at the beginning of its own transmission has to access it without disturbing the transmission already existing in the other slots and after the initial access is done its burst should be

placed in the proper location. The various methods available for this have been proposed in literature [20,21,22].

The initial acquisition can be done by a carrier burst or PN sequence method. The earlier method is to be used for INSAT.

2.2 Spread Spectrum Multiple Access

It is known from signal detection theory that for binary transmission of known signals in the presence of additive white Gaussian noise (AWGN) the error probability depends upon E_b/N_o ratio. Spreading the bandwidth of the signals will not degrade the performance of detection as long as the recovered energy of the signal remains the same as that of the original signal. This spreading of the bandwidth will reduce the capacity of a fixed bandwidth channel, but multiple access capability can be achieved. One of the purposes of spreading the signal is to make it look like a white Gaussian noise [23]. The spreading of the signal is done by some operation on the signal using Psuedo random codes. For detection, it is essential to have the exact inverse operation with the same code stored at the receiver.

One way to achieve both multiple access and random access and also make efficient use of the satellite repeater is to have all the users simultaneously use the entire repeater bandwidth. This can be accomplished by assigning each user a distinct code. The codes selected should have certain

desirable correlation properties. Each user then spreads his information with the help of the code and transmits it. The receiver employs a phase coherent correlator capable of locking onto the desired transmitted signals while rejecting others. The spreading of the information can be done in the following ways.

i) Direct sequence or psuedo random sequence, in which a carrier is modulated by a digital code sequence having a bit rate much higher than the information signal rate.

ii) Frequency hopping, in which the carrier frequency is shifted in a pattern dictated by a code sequence [24, 25].

iii) Pulsed-FM or chirp, in which a carrier is swept linearly over a wideband of frequencies during a given pulse [26].

We shall consider the direct sequence SSMA only.

2.2.1 Direct-sequence SSMA

Fig. 2.3 shows a block diagram of a spread-spectrum system in the most general form. At the transmitter, a carrier $A_0 \cos \omega_0 t$, is modulated, by any form of amplitude or angle modulation or a combination of both to produce $S_1(t) = A_1(t) \cos(\omega_0 t + \varphi(t)]$. This modulated signal is then multiplied by a time function $PN_1(t)$. This spreads the energy of $S_1(t)$ over a much larger bandwidth. The product signal is then transmitted as shown in Fig. 2.3 and received

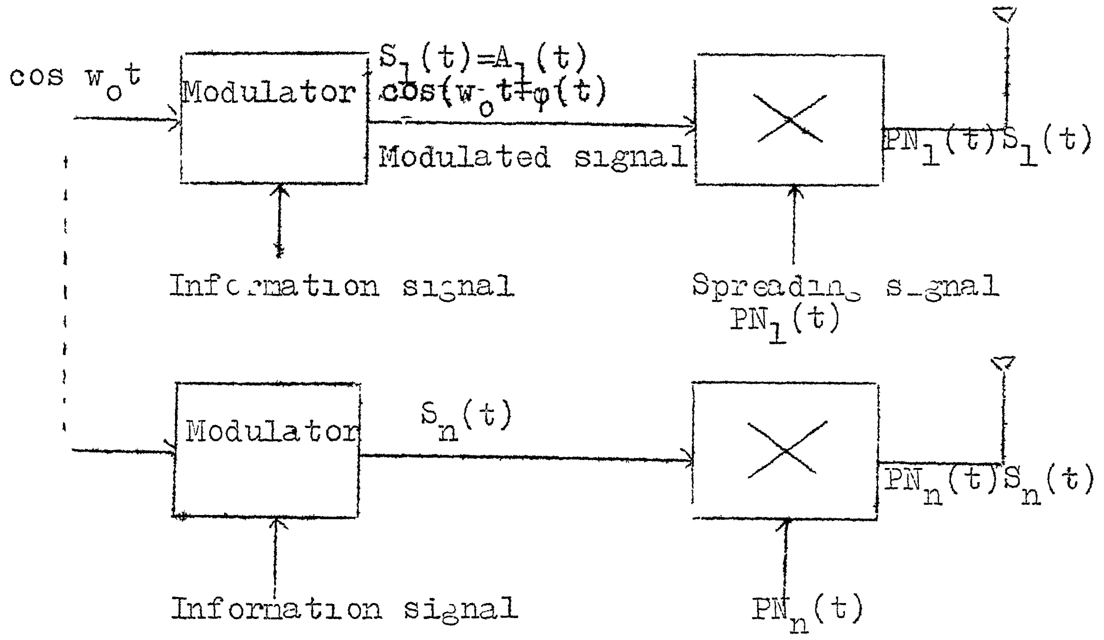


Fig. 2.3 Spread Spectrum Transmitter

at the receiver along with other spread signals $PN_2(t)\ S_2(t)$, ... $PN_n(t)\ S_n(t)$, from other transmitters, an intentional interfering signal $S'(t)$ and noise $n(t)$. So the signal received at the receiver can be represented by $PN_1(t)\ S_1(t) + PN_2(t)\ S_2(t)\ \ldots. + PN_n(t)\ S_n(t) + S'(t) + n(t)$ as shown in Fig. 2.4.

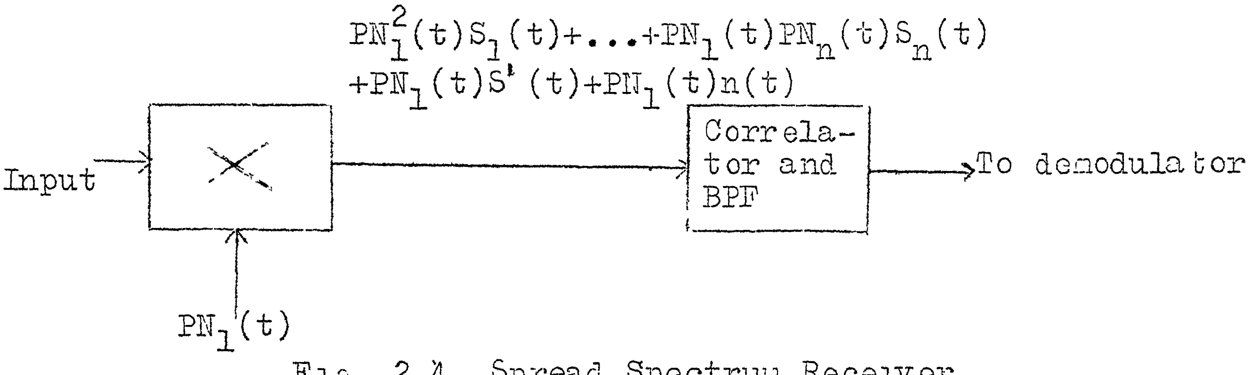


Fig. 2.4 Spread Spectrum Receiver

At the receiver after multiplication by $PN_1(t)$ the resulting signal is $PN_1^2(t)\,S_1(t) + \ldots + PN_1(t)\,PN_n(t)\,S_n(t) + PN_1(t)\,S'(t) + PN_1(t)\,n(t)$. The intentional interfering signal $S'(t)$ and noise have been spread over a widebandwidth by the multiplication with $PN_1(t)$. If $PN_1(t)$ is chosen such that $PN_1^2(t) = 1$ and $PN_1(t)\,PN_j(t) = 0$ (a correlation operation) where $j = 1, 2 \ldots n$ and if the multiplier output is passed through a correlator and bandpass filter then the receiver would be able to extract only the wanted signal. $S'(t)$ and $n(t)$ now band spread, will have very little energy in the information bandwidth. The wanted signal has now collapsed back to original information bandwidth [27].

If the information to be transmitted is in binary form, the information sequence is modulo-2 added to the code sequence. (This is equivalent to waveform multiplication) as shown in Fig. 2.5. This added sequence is modulated by the carrier, say by using phase shift keying.

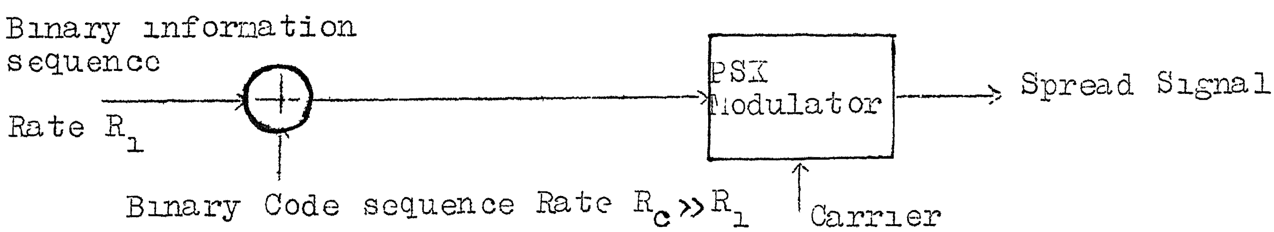


Fig. 2.5 Spread Spectrum Transmitter for Binary Information Sequence

2.2.2 Code sequence aspects

The easiest way of generating PN sequences is with the help of shift registers. The linear feedback shift register (LFSR) uses modulo-2 addition logic in the feedback path as shown in Fig. 2.5.

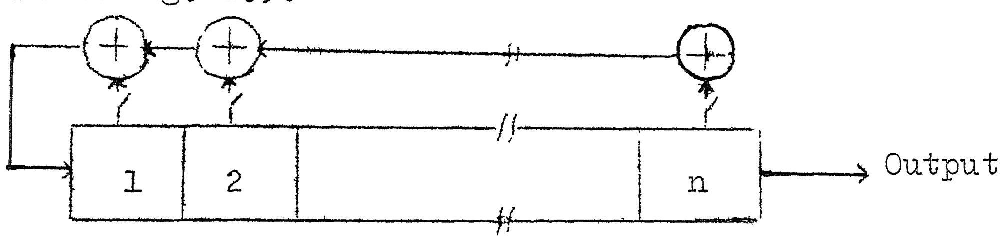


Fig. 2.5 Linear Feedback Shift Register

If the wire tappings are chosen according to some irreducible polynomial of degree n, this arrangement will produce a sequence of period $2^n - 1$, where n is the number of stages in the shift register. A sequence having a period $p = 2^n - 1$ is called a maximal - length sequence. Properties of maximal - length sequences are briefly described in Appendix 'A'. The major problem with linear sequences is that they are decipherable once (2n+1) successive bits are known. To increase crytographic security, a non-linear logic (AND, OR, INVERT, etc) can be added in a feedforward fashion as shown in Fig. 2.6. This is known as nonlinear feedforward logic (NFFL) [14].

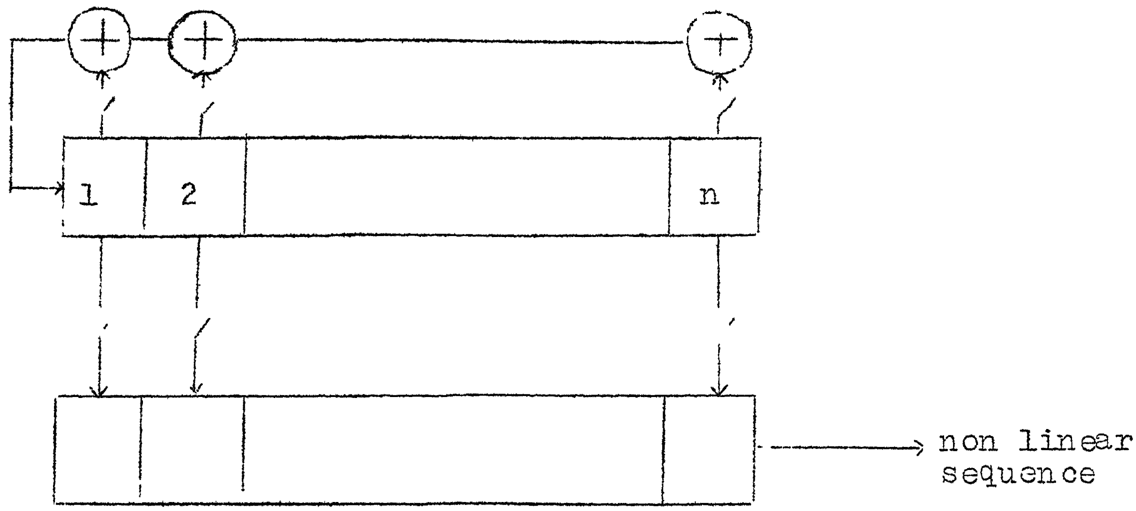


Fig. 2.6 Nonlinear Feedforward Logic

2.3 Correlation Functions and Power Spectra of PN Sequences

A normalised autocorrelation function for a function of time is given by

$$\Gamma(\tau) = \lim_{T\to\infty} (1/T) \int_0^T F(t)\, F(t+\tau)dt \qquad (2.2)$$

Normalised cross-correlation of two functions of time is given by

$$\Gamma(\tau) = \lim_{T\to\infty} (1/T) \int_0^T F_1(t)\, F_2(t+\tau)dt \qquad (2.3)$$

For binary sequences, correlation function can be determined by noting that the variable τ in eqns. 2.2 and 2.3 is the number of bits by which the second sequence is shifted with respect to the first. Then by comparing the two sequences bit by bit, the normalised correlation function

is determined from

$$\rho = \frac{\text{Number of agreements - number of disagreements}}{\text{Number of digits in the period of sequence}} \qquad (2.4)$$

Maximal length sequences has an autocorrelation of unity at zero shift and $-\frac{1}{p}$ at all other values of shift, where p is the length of the sequence.

The power spectrum of a PN sequence with an autocorrelation function as given above is given by

$$S(\omega) = \left(\frac{p+1}{p}\right)^2 \left[\frac{\sin \omega t_o/2}{\omega t_o/2}\right]^2 \sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty} \delta(\omega - 2\pi n/pt_o) + \frac{1}{p^2}\,\delta(\omega) \qquad (2.5)$$

where p is the period of the sequence, to is the period of one digit of the binary waveform, and $\delta(\cdot)$ is the dirac delta function. The autocorrelation function and power spectrum envelope for binary sequences are as shown in Fig. 2.7.

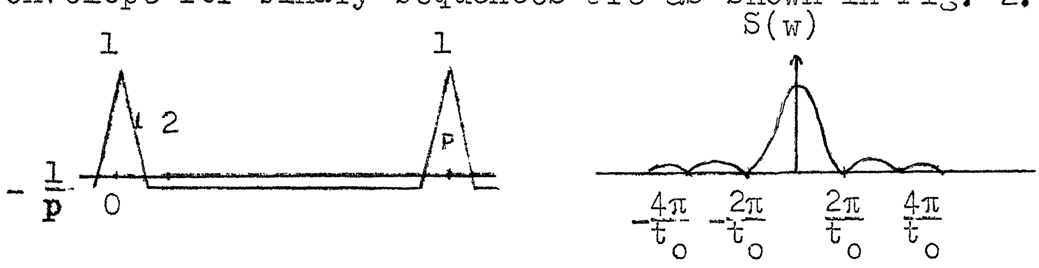


Fig. 2.7 Autocorrelation and Power Spectrum Envelope

Equation 2.5 shows that the spectrum is a line spectrum. There is a scale factor inversely proportional to the period of the sequence. Thus doubling the period of the sequence

will double the number of line spectra but the power in each is halved, since the total power is constant. As seen from the Fig. 2.7 the spreading is determined by the code clock. The dc power can be reduced by increasing the period of the sequence. Since dc power is proportional to $\frac{1}{p^2}$.

The cross-correlation of the code selected, with the other codes is an important property which should be investigated fully. The cross-correlation peaks should be as small as possible. Though maximal-length sequences have good correlation properties, there are Gold-codes which have well-defined correlation characteristics. These codes are produced by modulo-2 adding the outputs of two n-stage shift registers wired to produce maximal length sequences as shown in Fig. 2.8.

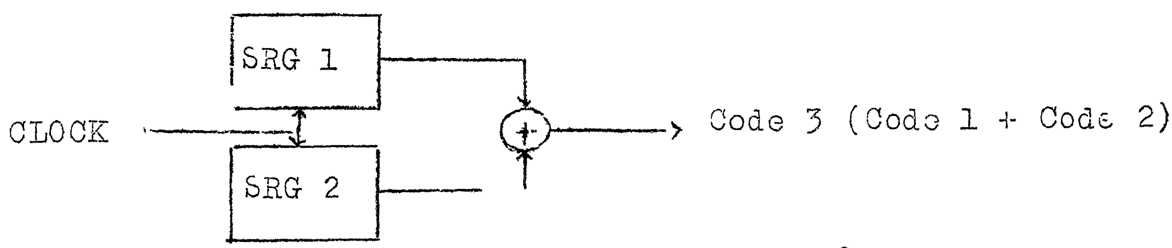


Fig. 2.8 Gold Code Sequence Configuration

2.4 Interference Rejection Capability

Since 90 percent of the total power in direct sequence spread spectrum is contained in a bandwidth equal to twice the code clock rate, the bandwidth of the spread spectrum can be taken as $2R_c$ where R_c is the code clock rate [28]. The mixture of wanted spread signal and interference which is

received is correlated with the replica of spreading signal used at the transmitter. The correlation process 'despreads' the information signal to the original bandwidth and the interference is spread to a wider bandwidth. This is passed through a narrow band filter. This process is shown in Fig. 2.9.

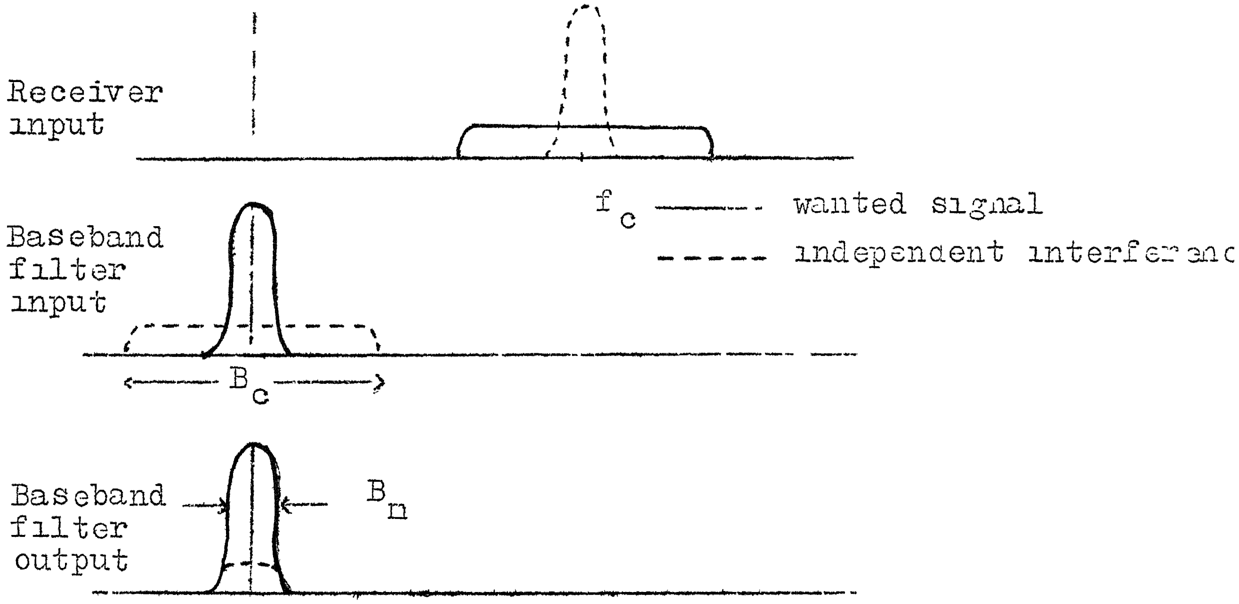


Fig. 2.9 Interference Rejection

The larger the ratio of the bandwidth of the spread signal t that of the inform tion signal is, the smaller will be the effect of unwanted interference. At the correlator input, the signal-to-interference ratio is approximately

$$(S/I)_{in} = S/I\ B_c$$

while at the output of the correlator and narrow-band filter it is

$$(S/I)_{out} = S/I\ B_n$$

where I is the spectral power density of the unwanted signal and B_c and B_n are respectively the spread spectrum and information bandwidths.

The processing gain is given by

$$G_p = \frac{(S/I)_{out}}{(S/I)_{in}}$$

$$= (\frac{B_c}{B_n})$$

CHAPTER 3

COMPUTER SIMULATION OF TDMA AND SSMA LINKS

The satellite links using time division and spread spectrum multiple accesses were simulated using DEC-1090 system. For both these accesses the carrier modulations of BPSK, DPSK and QPSK were chosen.

3.1 TDMA Simulation

The receiver used in BPSK modulation can be an integrate and dump filter since inter-symbol interference (ISI) effect is negligible in a satellite channel. Since both baseband and PSK transmissions have the same probability of error [29] the baseband simulation instead of carrier simulation was carried out. The flow charts for BPSK and DPSK simulation are as given in Fig. 3.1 and 3.2 respectively. The simulation was carried out for various values of E_b/N_o and the results obtained for BPSK, and DPSK and QPSK are as shown in Figs. 3.3, 3.4 and 3.5 respectively. The computer listings of the programmes used for BPSK and DPSK, TDMA links are given in Appendix B and C respectively. The simulation for QPSK is similar to that of BPSK except that $2x10^5$ bits were transmitted and the symbol error rate was calculated.

The results obtained in the simulation match closely with the theoretically predicted results for BPSK, DPSK and

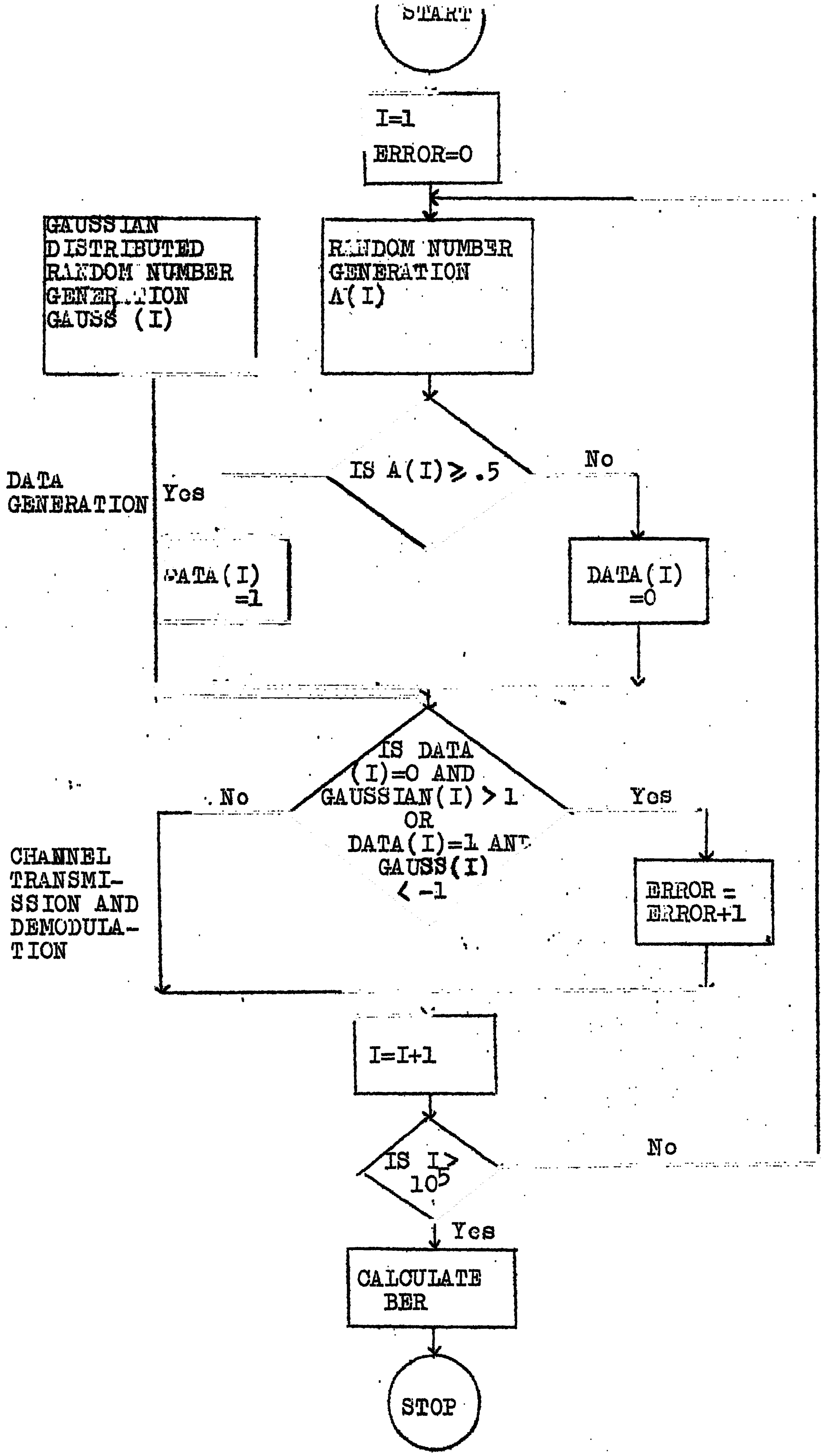
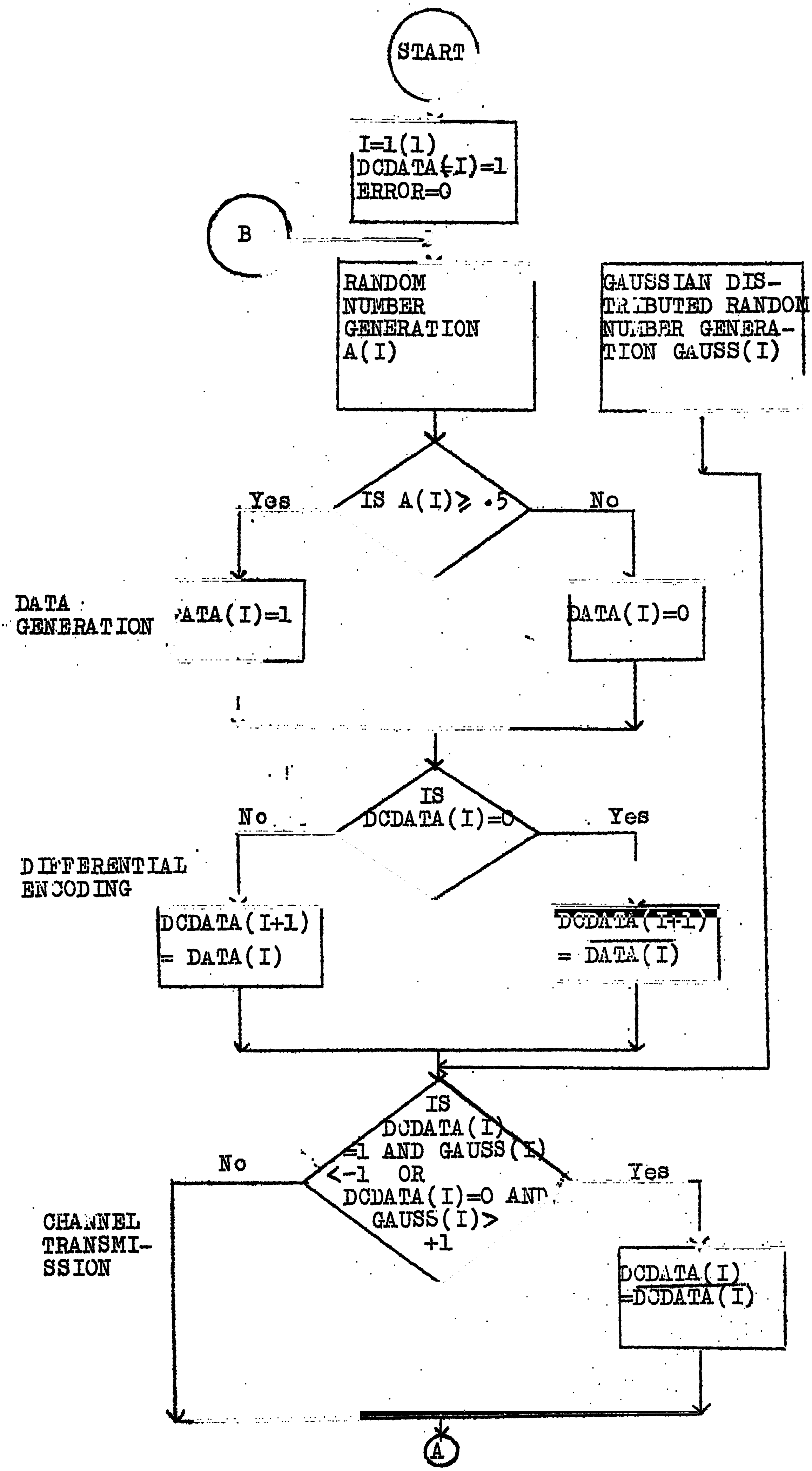


Fig. 3.1 Flow Chart for PCM/BPSK/TDMA Transmission


START
I=1(1)
DCDATA(I)=1
ERROR=0
B
RANDOM NUMBER GENERATION A(I)
GAUSSIAN DISTRIBUTED RANDOM NUMBER GENERATION GAUSS(I)
IS A(I)≥ .5
Yes
No
DATA GENERATION
DATA(I)=1
DATA(I)=0
IS DCDATA(I)=0
No
Yes
DIFFERENTIAL ENCODING
DCDATA(I+1) = DATA(I)
DCDATA(I+1) = DATA(I)
IS DCDATA(I) =1 AND GAUSS(I) <-1 OR DCDATA(I)=0 AND GAUSS(I)> +1
No
Yes
CHANNEL TRANSMISSION
DCDATA(I) =DCDATA(I)
A

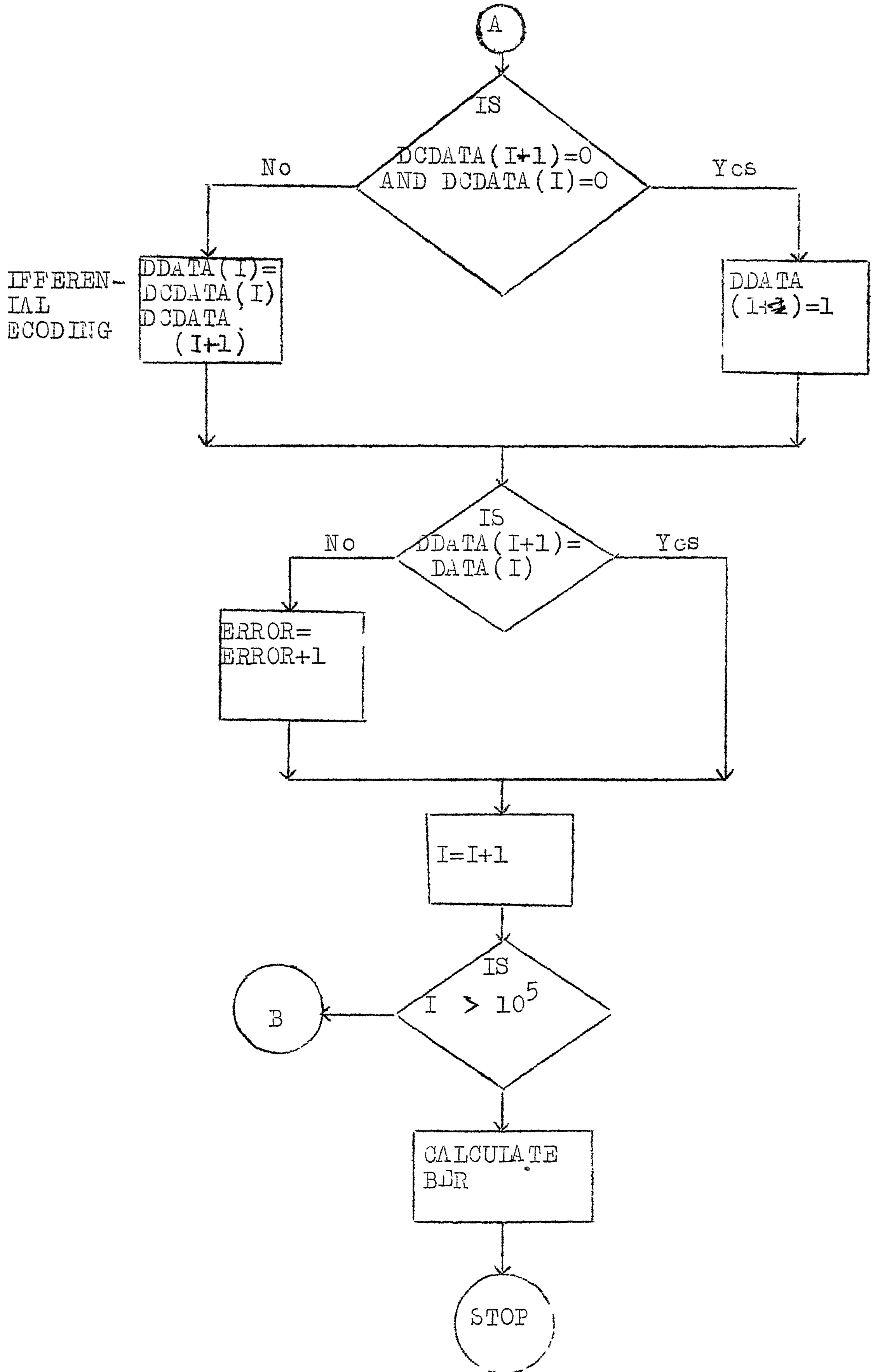


Fig. 3.2 DPSK/TDMA Simulation Flow Chart DPSK

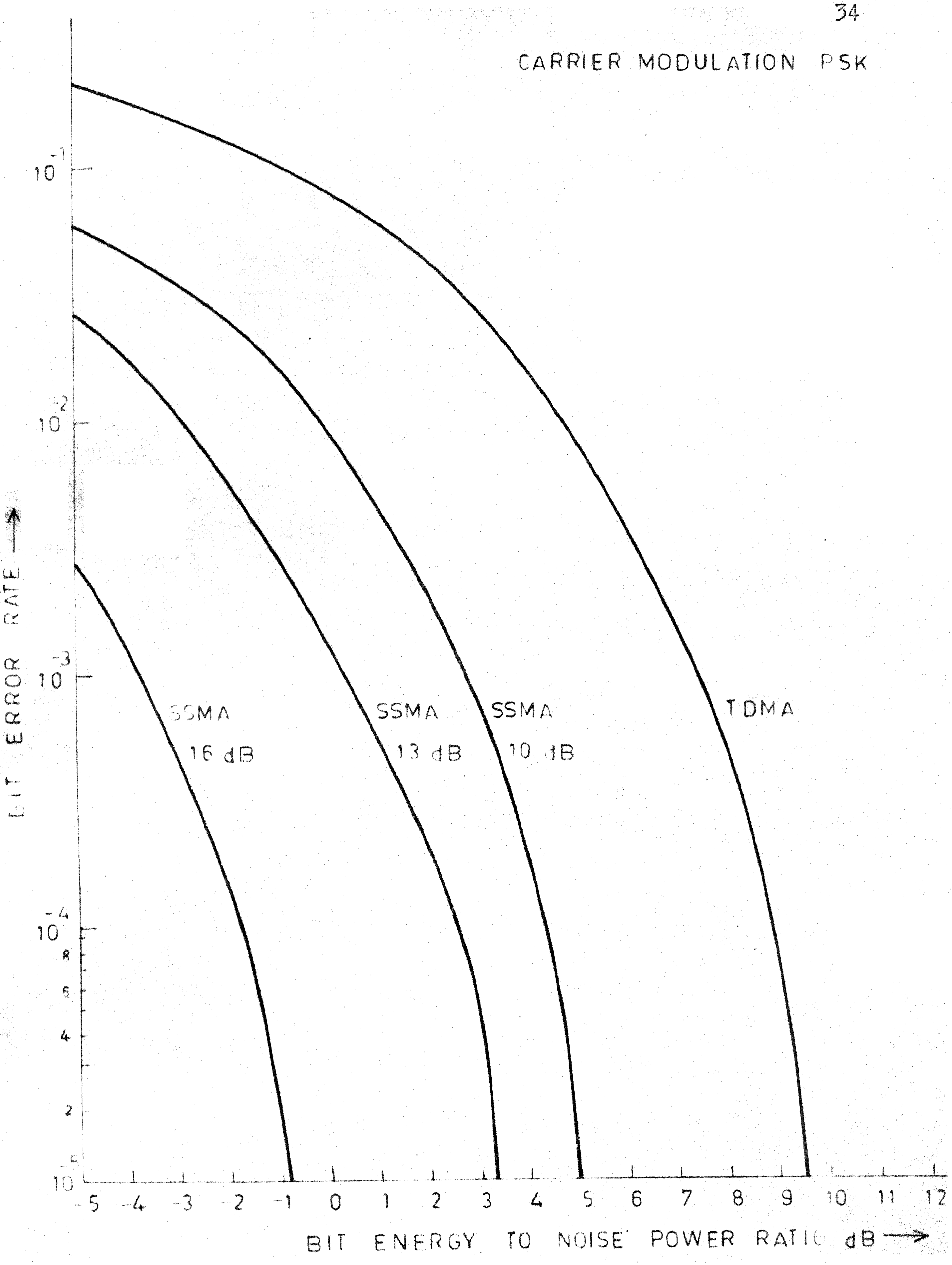
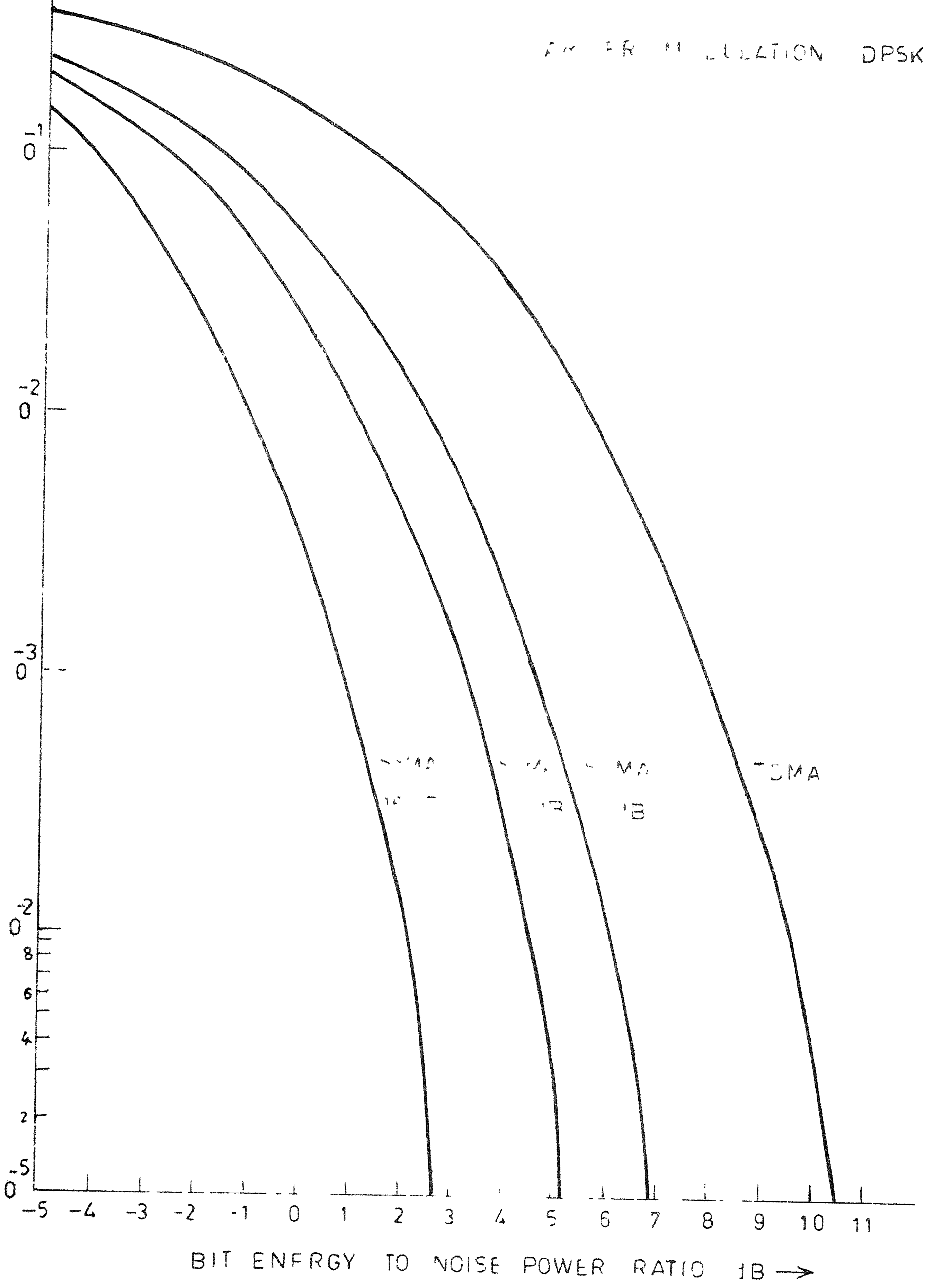


FIG. 3.3 BPSK SIMULATION RESULTS


DPSK
10⁻¹
10⁻²
10⁻³
8
6
4
2
10⁻⁵
−5 −4 −3 −2 −1 0 1 2 3 4 5 6 7 8 9 10 11
BIT ENERGY TO NOISE POWER RATIO dB →

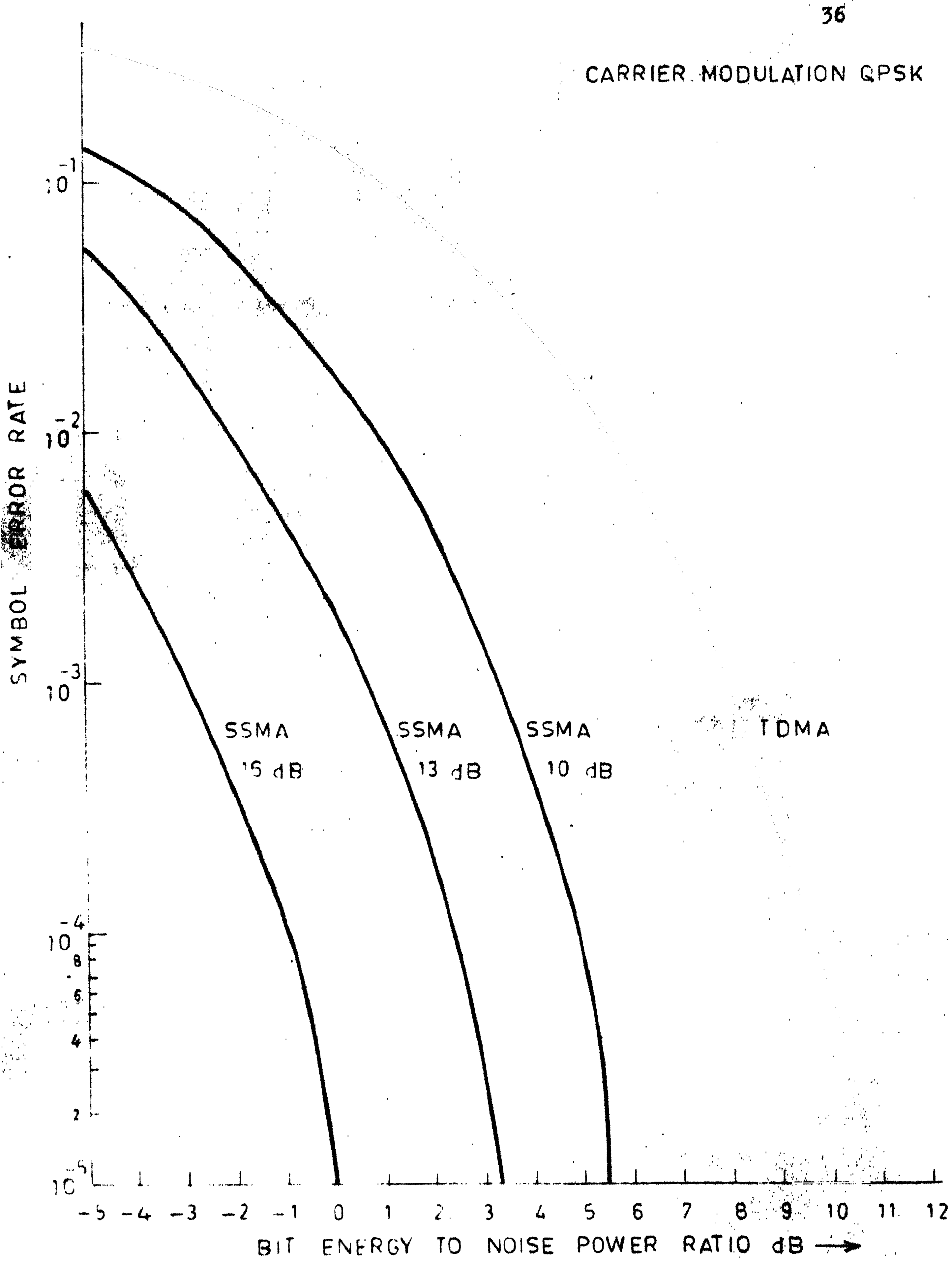


FIG.3.5 QPSK SIMULATION RESULTS

QPSK as given in [30]. The result for QPSK is given as symbol error rate versus bit signal energy to noise power ratio.

3.2 SSMA Simulation

Here direct sequence spread spectrum method was used for simulation. Maximal length sequences of length $2^n - 1$ for any n is obtained by LFSR by selecting a suitable primitive irreducible polynomial. Ref. [31] gives a list of irreducible polynomials of degree n = 1,2, ... 32. For example $X^{11} + X^9 + X^4 + X + 1$ is a primitive irreducible polynomial of degree 11, which when wired as shown in Fig. 3.6 will give a PN sequence of length $2^{11} - 1 (= 2047)$.

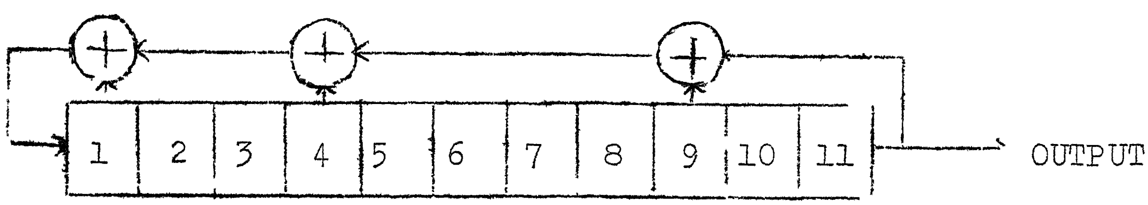


Fig. 3.6 (11,9,4,1) Feedback Shift Register

2.1 Autocorrelation and cross-correlation of Sequence (11,9,4,1

The PN sequence generated by (11,9,4,1) connection was found to be a maximal length sequence with autocorrelation value of 1 for zeroshift and $-\frac{1}{2047}$ for all other shifts.

The cross-correlation with other maximal length sequences of length 2047 generated by (11,9,8,3), (11,8,5,2), (11,7,3,2), (11,10,3,2), (11,6,5,1), (11,5,3,1), (11,8,6,2) were studied and the maximum cross-correlation peak was found to be $\frac{127}{2047}$

which gives an index of discrimination of 1920.

2.2 SSMA System

Since usual receiver noise, jamming (except repeater jamming) and unrelated interference can be modelled as a widesense stationary independent process; white Gaussian noise is used in the simulation to model the interference. Simulation of SSMA was carried out for the processing gain values of 10,13 and 16 dB.

The SSMA system used for simulation is as shown in Fig. 3.7.

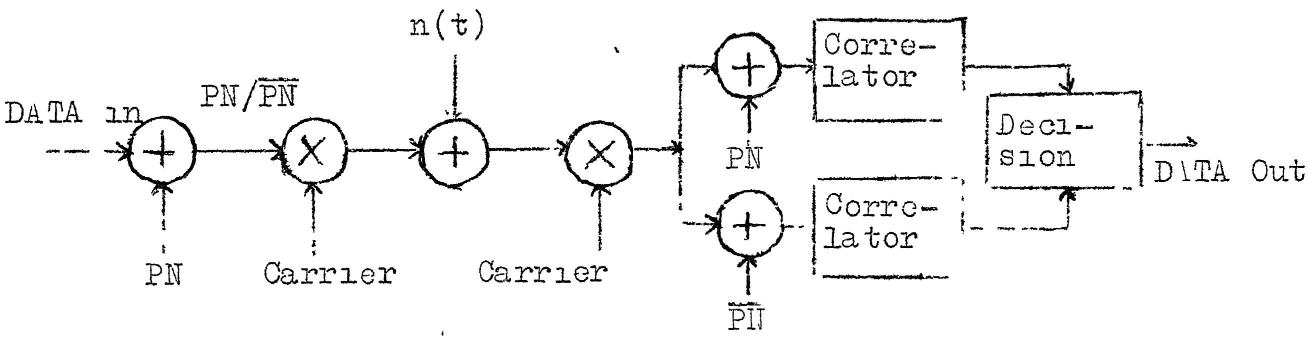
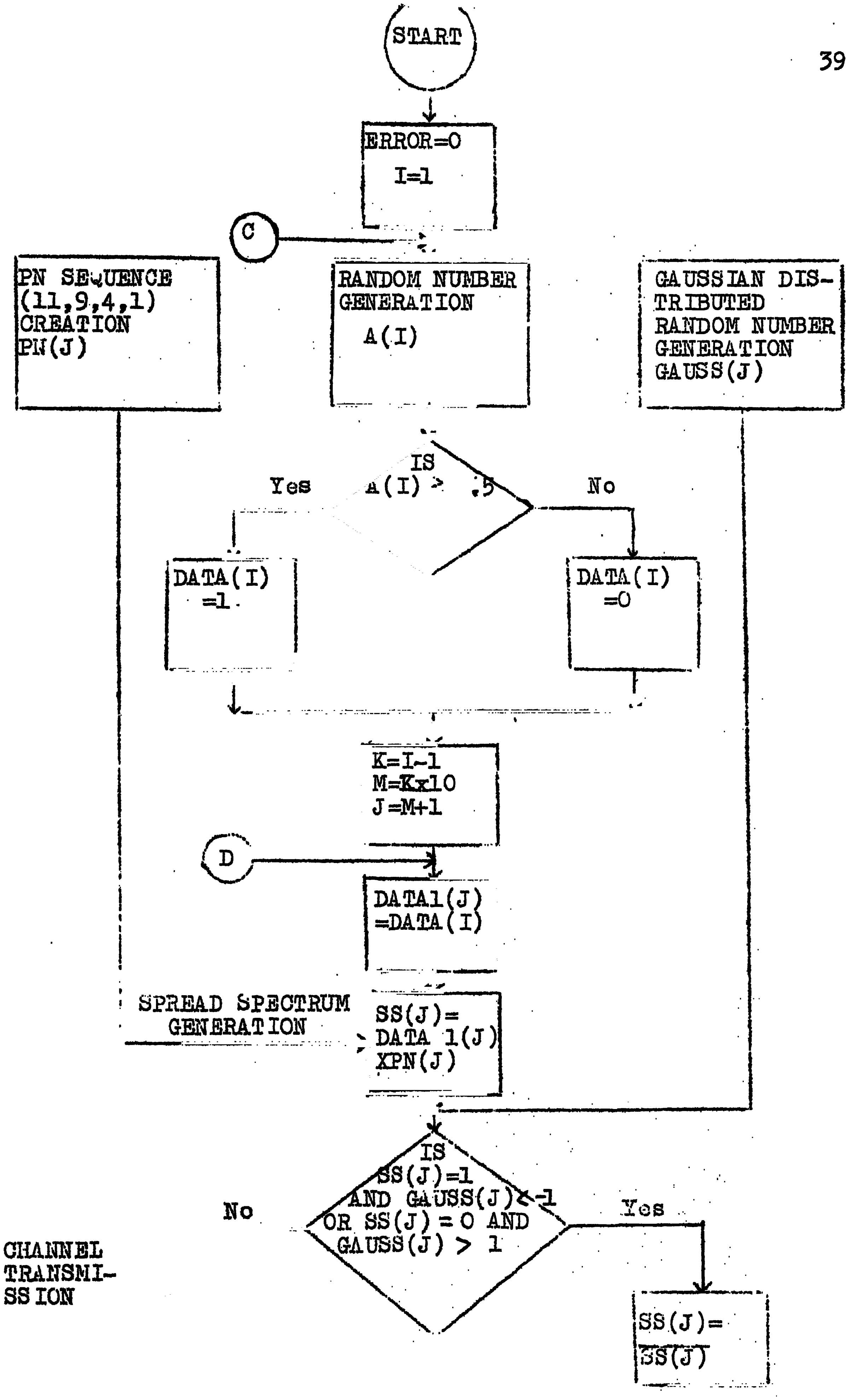
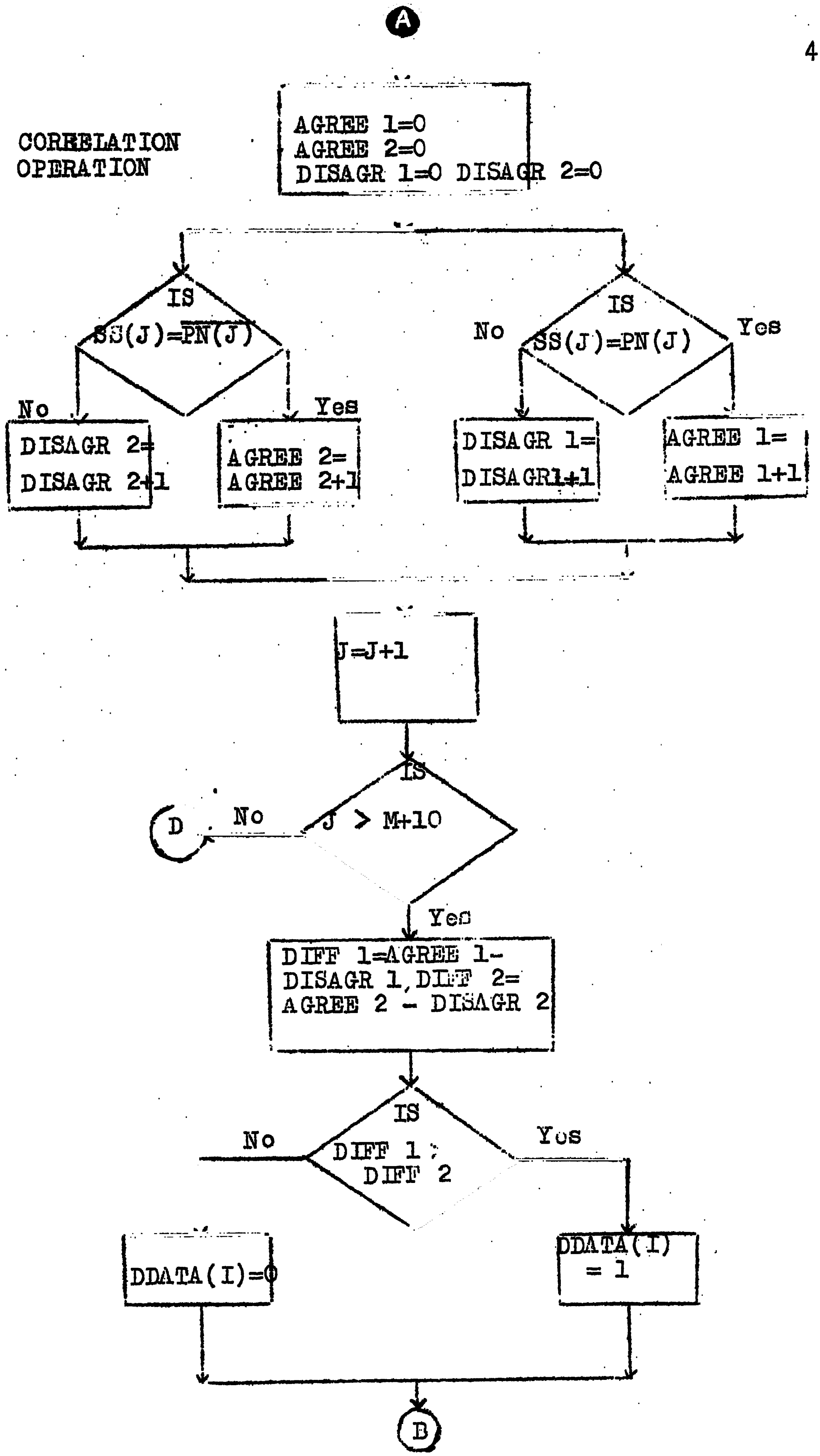


Fig. 3.7 SSMA System Used for Simulation

2.3 Results

As in the case of TDMA baseband simulation (instead of carrier simulation) using BPSK, DPSK and QPSK transmissions were carried out. The flow chart for PCM/BPSK/SSMA simulation is as shown in Fig. 3.8. The results of simulation are presented in Fig. 3.3 and the corresponding listing of the computer program given as Appendix 'D'.


START
ERROR=0
I=1
C
PN SEQUENCE
(11,9,4,1)
CREATION
PN(J)
RANDOM NUMBER
GENERATION
A(I)
GAUSSIAN DIS-
TRIBUTED
RANDOM NUMBER
GENERATION
GAUSS(J)
IS
A(I) > .5
Yes
No
DATA(I)
=1
DATA(I)
=0
K=I-1
M=Kx10
J=M+1
D
DATA1(J)
=DATA(I)
SPREAD SPECTRUM
GENERATION
SS(J)=
DATA 1(J)
XPN(J)
IS
SS(J)=1
AND GAUSS(J)<-1
OR SS(J) = 0 AND
GAUSS(J) > 1
No
Yes
CHANNEL
TRANSMI-
SSION
SS(J)=
$\overline{SS(J)}$


A
CORRELATION OPERATION
AGREE 1=0
AGREE 2=0
DISAGR 1=0 DISAGR 2=0
IS SS(J)=PN(J)
No
Yes
DISAGR 2=
DISAGR 2+1
AGREE 2=
AGREE 2+1
IS SS(J)=PN(J)
No
Yes
DISAGR 1=
DISAGR1+1
AGREE 1=
AGREE 1+1
J=J+1
IS J > M+10
No
D
Yes
DIFF 1=AGREE 1-
DISAGR 1, DIFF 2=
AGREE 2 - DISAGR 2
IS DIFF 1 > DIFF 2
No
Yes
DDATA(I)=0
DDATA(I)
= 1
B

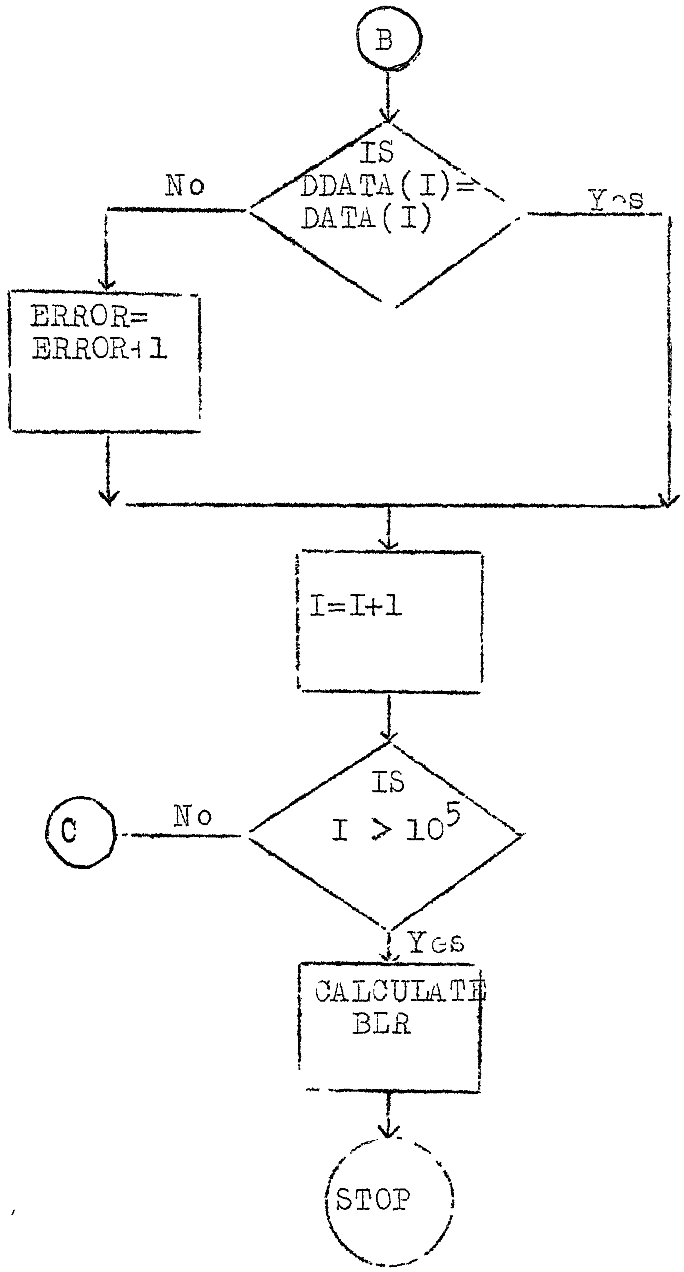


Fig. 3.8 BPSK/SSMA Simulation Flow Chart

The improvement obtained by SSMA over TDMA for the various transmission modulations at the error rate of 10^{-4} is as shown in Fig. 3.9. It can be seen that the E_b/N_0 required to achieve an error rate of 10^{-4} in BPSK/SSMA is 4.4 dB which is an improvement of 4.4 dB over TDMA. This value has been used in the power budget calculations.

Table 3.1 gives an idea of the timings involved in the simulation of the systems over DEC-1090 system. Timings are given in min.sec. These timings are for the simulation of 10^5 bits in BPSK and DPSK and $2x10^5$ bits in QPSK.

Access		Modulation		
		BPSK	DPSK	QPSK
TDMA		0 :18	0 :24	0 :37
SSMA	10 dB	2 :15	2 :21	4 :33
	13 dB	4 :27	4 :39	8 :56
	16 dB	8 :50	9 :02	17 :02

Table 3.1 Computer Timings

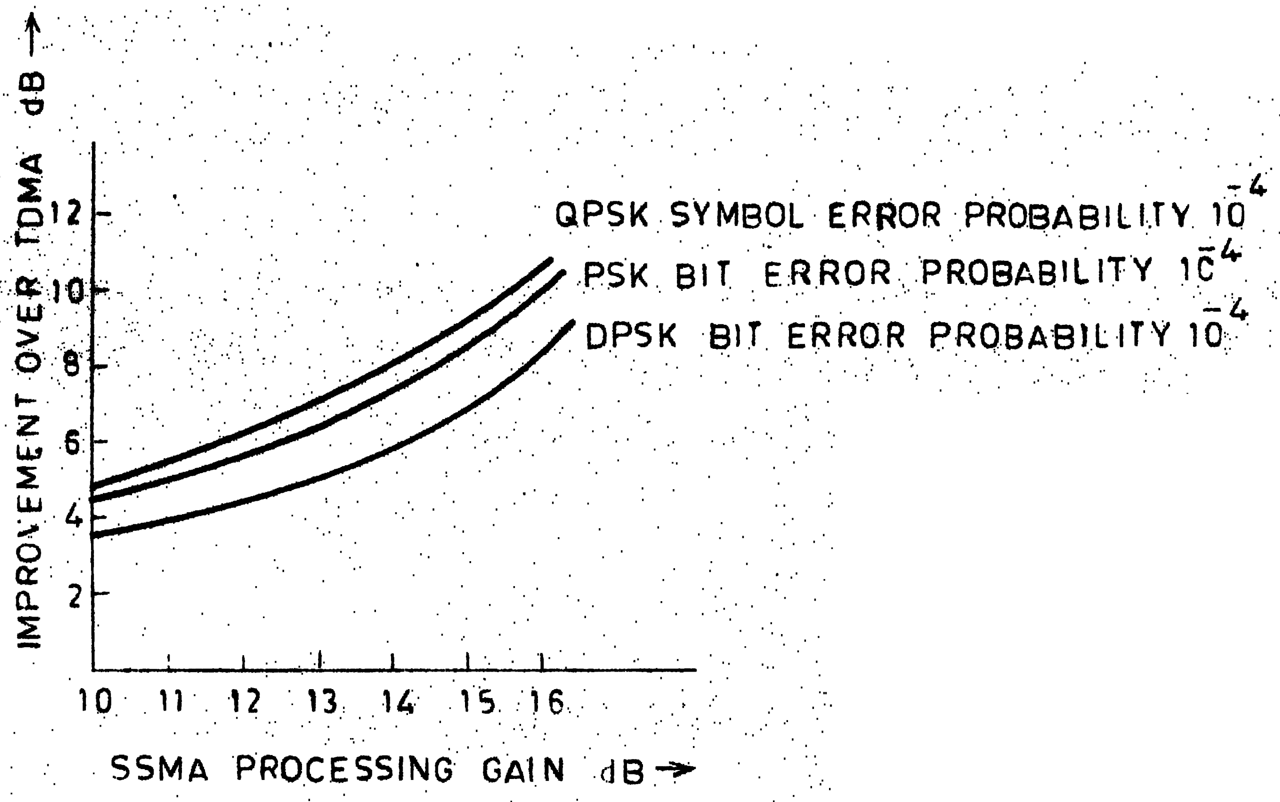


FIG. 3.9 SSMA IMPROVEMENT OVER TDMA

CHAPTER 4

ON-BOARD REGENERATION

The advantages of on-board regeneration have been pointed out in Chapter 1. Now we will consider various configurations for uplink and downlink accessess and modulation techniques to be used therein. First we will consider the same type of accesses on both uplink and downlink, and then different types of accesses for each of the links and finally some hybrid schemes. From these various configurations we will select a scheme suitable for military requirements.

4.1 Configurations Using TDMA for Both Links

For an on-board regeneration scheme using PCM/PSK/TDMA for both links, an ideal repeater would be as shown in Fig. 4.1.

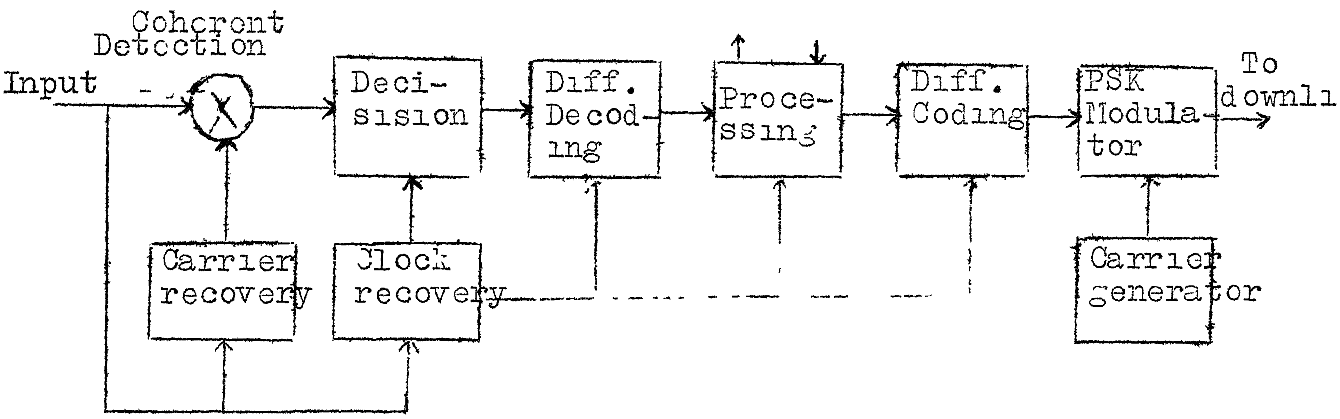


Fig. 4.1 Configuration of Ideal Regenerative Repeater

Here coherent detection with differential coding is employed for the uplink. Functions performed by the various

subblocks in the figure can be realized with sufficient reliability. But fast carrier recovery and clock recovery for each burst are very critical and these recoveries have to be done within a few symbols for each burst, otherwise signal degradation will result. So to ease this problem one may omit either carrier recovery or clock recovery or both and consequently make the onboard regenerator configuration simpler. Now we will consider the various schemes by omitting either one or both.

4.1.1 Regenerative scheme without carrier recovery

Carrier recovery realization with sufficient stability poses the maximum problem, specially when the constraints are in terms of lesser complexity, low power consumption and lesser weight. We can make the onboard regenerator less complex by omitting carrier recovery. Now with the omission of carrier recovery, differentially coherent detection, seems to be an ideal alternative. But this method requires an additional power of 0.5 dB for biphase signal (2.5 dB for 4 phase).

But uplink power is not a premium factor and the ground transmitter must provide this additional power. This scheme is shown in Fig. 4.2.

But this type of detection in turn requires that the one symbol delay be achieved with sufficient accuracy, otherwise the delay-time variation will result in phase error of

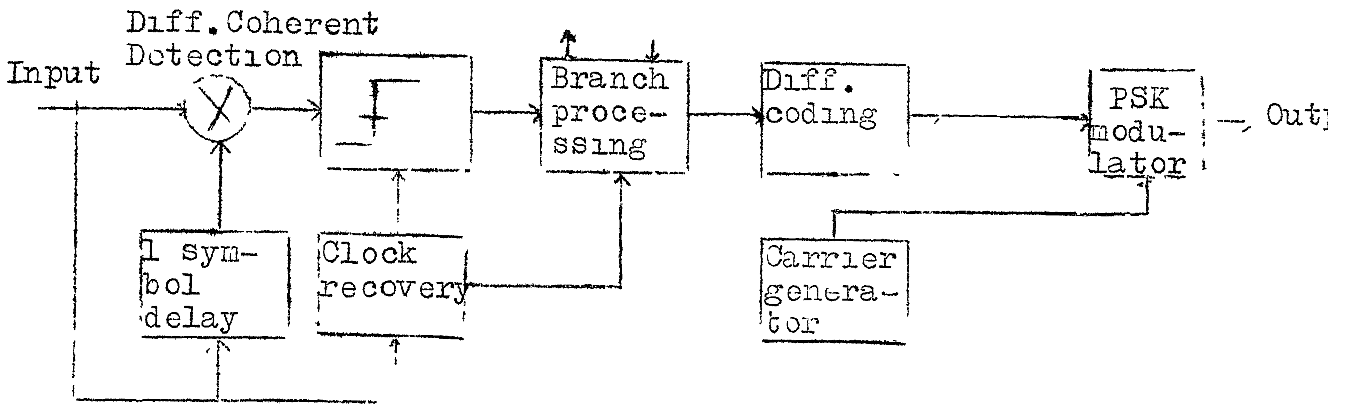


Fig. 4.2 Configuration with Omission of Clock Recovery

the reference signal and consequent degradation in performance. The phase error is given by

$$\therefore P = \frac{f_c}{f_s} \quad E_t \times 360 \text{ (degrees)} \tag{4.1}$$

where f_c is the carrier frequency, f_s is the symbol frequency and E_t is the delay-time variation. Differential encoding for downlink is optimal because of two factors. One is the additional power requirement and second is that since the carrier is coherent over all the bursts the coherent PSK can be rather easily used.

4.1.2 Regenerative Scheme without clock recovery

This regenerative scheme is as shown in Fig. 4.3.

This scheme is not very useful, since the critical element of carrier recovery is not resolved. Also onboard processings which require clock cannot be performed in this case. But

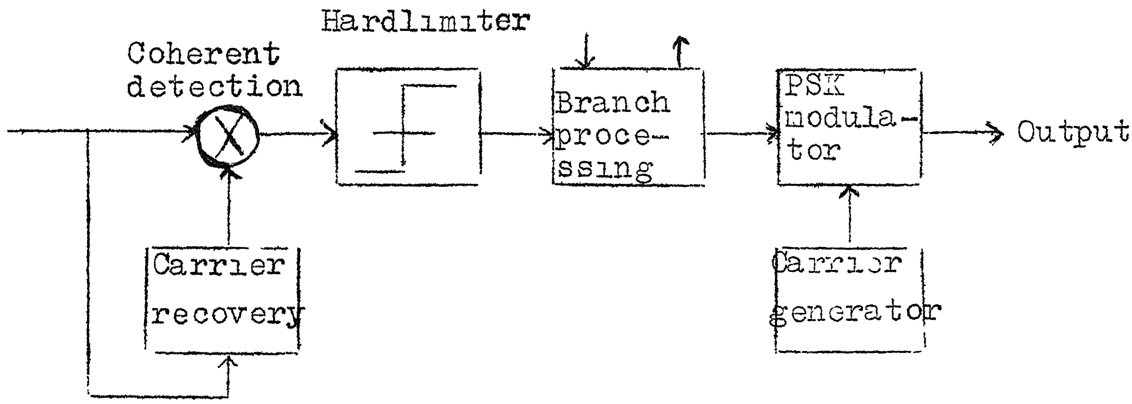


Fig. 4.3 Configuration with omission of Clock Recovery

carrier phase ambiguity can be resolved by using differential encoding at the ground transmitter and differential decoding at the ground receiver.

4.1.3 <u>Regenerative scheme without both carrier and clock recovery</u>

The configuration becomes very simple without both carrier and clock recovery and can be shown as in Fig. 4.4.

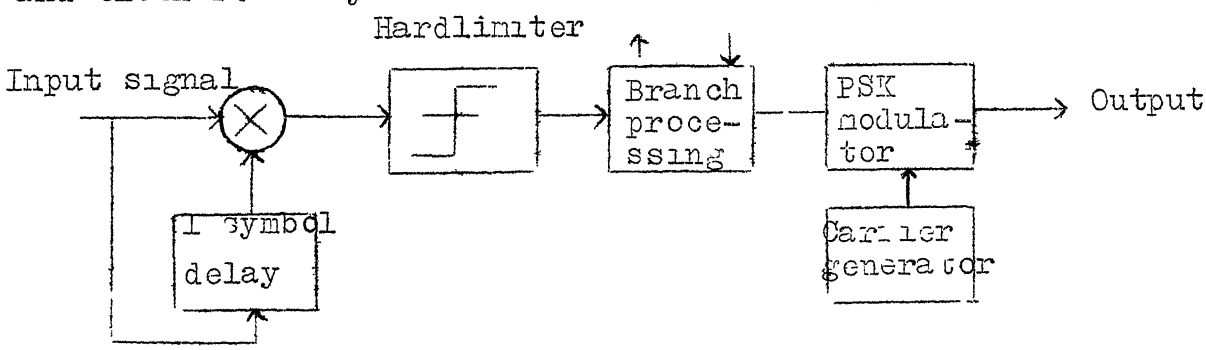


Fig. 4.4 Configuration with Both Clock and Clock Recovery omission

This scheme cannot be applied to 4 phase PSK because of the large timing jitter. But in the case of two phase PSK the jitter is tolerable [1]. Similar to the scheme in 4.1.2

any processing which requires clock cannot be performed onboard in this case. So differential encoding cannot be used for the downlink. But doubly differential encoding [32] can be done at the earth station, otherwise coherent PSK is the normal downlink format.

4.1.4 Advantages and disadvantages

We have discussed the various configurations of using TDMA for both uplink and downlink. The frame efficiency for uplink as given by eqn. 2.1 can be increased by omitting either carrier recovery or clock recovery or both. This is because the additional dummy symbols in front of each burst for either carrier or clock recovery or both are not required. On the downlink since the carrier is coherent over all the bursts even if coherent demodulation is employed the carrier recovery bits are not required for each burst.

Since a satellite antenna 'sees' a large portion of the earth any transmitter within this portion can cause effective interference, if TDMA uplink is employed. Hence a TDMA uplink is not suitable from a military point of view.

4.2 Configuration Using SSMA for Both Links

As discussed in Section 2.4 spread spectrum modulation gives immunity from interference. Hence SSMA links are attractive from the point of view of secure communication. The configuration using SSMA for both up and down links is as shown in Fig. 4.5.

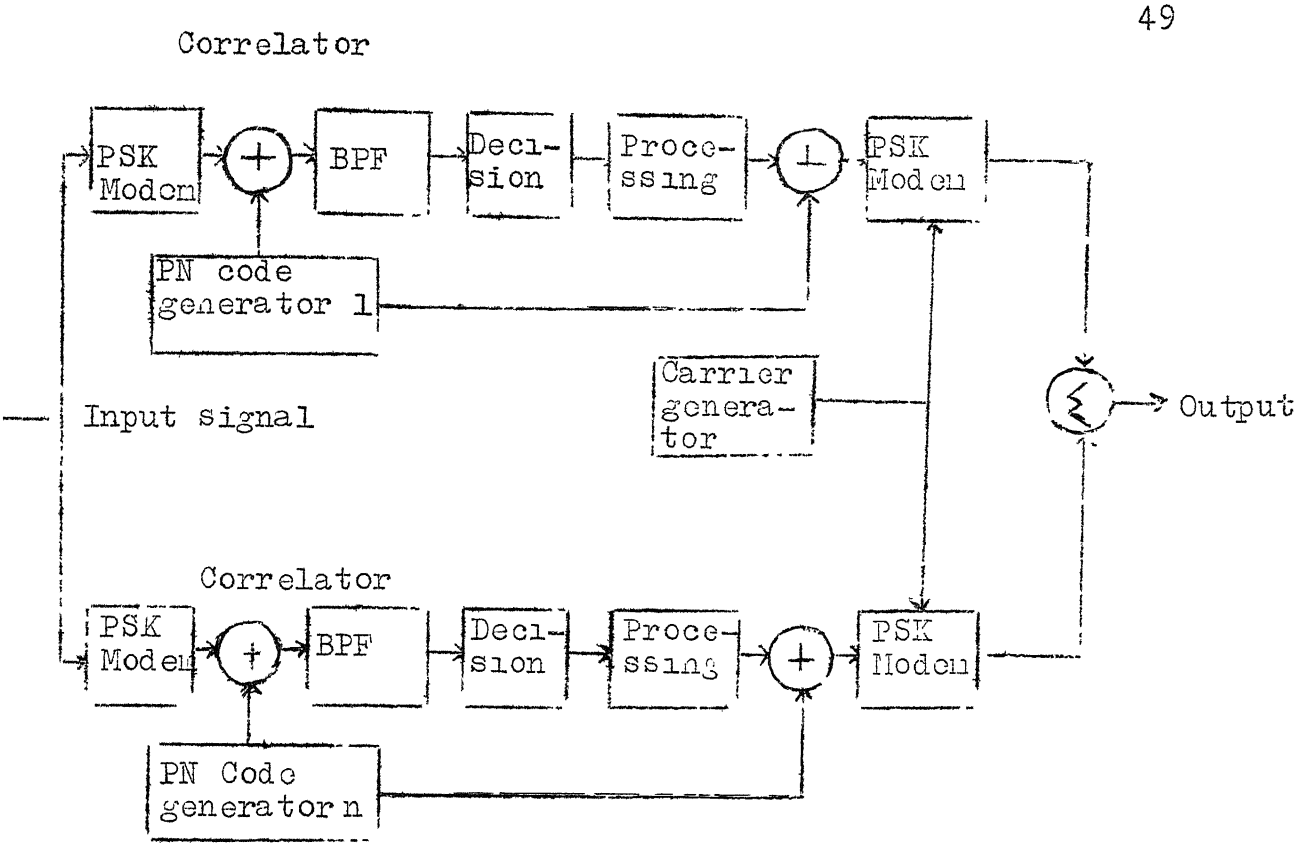


Fig. 4.5 SSMA for Uplink and Downlink

The SSMA uplink is advantageous from the point of view of interference removal. But a SSMA downlink is not attractive due to the following reasons. The difficult task of code synchronization has to be performed at the ground receiver which increases the ground receiver complexity. We would like to keep the ground receiver as simple as possible. Further little advantage is gained in having spread spectrum downlink because the distances involved are such that a spread spectrum signal cannot protect the receiver from interference that is close by (say powerful narrowband jamming) when the satellite downlink transmitter is 35,800 Kms away. Each accessing user has to use a separate PN code. This will result in slight degradation of performance due

to the cross-correlation noise due to the other accesses.

4.3 Configurations Using Different Types of Accesses for Uplink and Downlink

Since the technique of SSMA for both uplink and downlink does not offer any significant advantage, we will now consider different types of accesses for the links and see the advantages and disadvantages offered by these combinations. But a scheme with TDMA uplink and SSMA downlink can be outrightly rejected as it does not give uplink interference protection and also because the ground receiver becomes complex.

4.3.1 SSMA uplink and PSK/FDMA downlink

Spread spectrum multiple access is used on the uplink because of its interference rejection capabilities. For uplink the PN codes used by each ground station should be produced from the feedback shift register of same length but with various feedback connections producing maximal length sequences. The uplink carrier frequency is the same for all the accesses. On-board the signal is brought down to baseband using correlation operation and processing is done on the baseband if needed. After this the signals meant for various stations should be sent downlink in such a manner as not to interfere with each other. One way is to send them downlink using PSK modulation on various carriers. This system requires that the different ground stations be tuned to different frequencies and hence a

fast reconfiguration is difficult. The onboard regenerator for this scheme is as shown in Fig. 4.6.

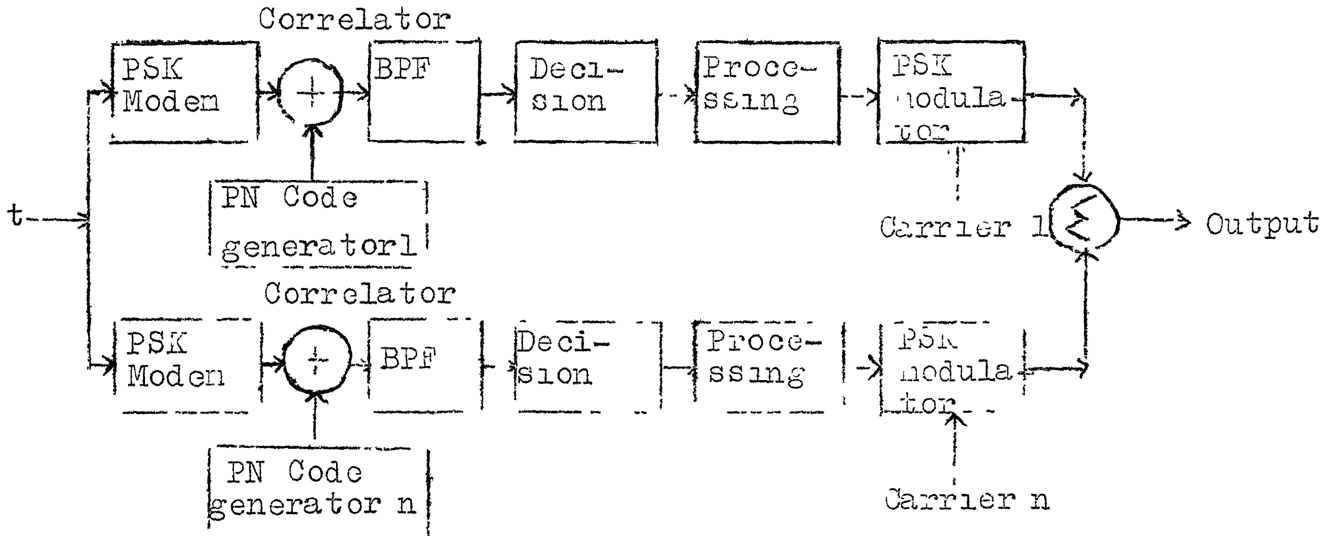


Fig. 4.6 Configuration Using SSMA Uplink and FDMA Downlink

4.3.2 SSMA Uplink and PSK/TDMA Downlink

In this scheme also the uplink is SSMA and accesses by various stations is done with the help of PN codes of same length. The schematic is as shown in Fig. 4.7. After base-band recovery is done onboard, to control downlink error rate, error correcting codes may also be introduced in the branch processing. Since the clocks received from the various stations on uplink may not be synchronous, retiming of the signals may be done onboard. To avoid interference between the signals on the downlink, signals meant for various stations are sent in bursts on the same carrier. The scheme is as shown in Fig. 4.7.

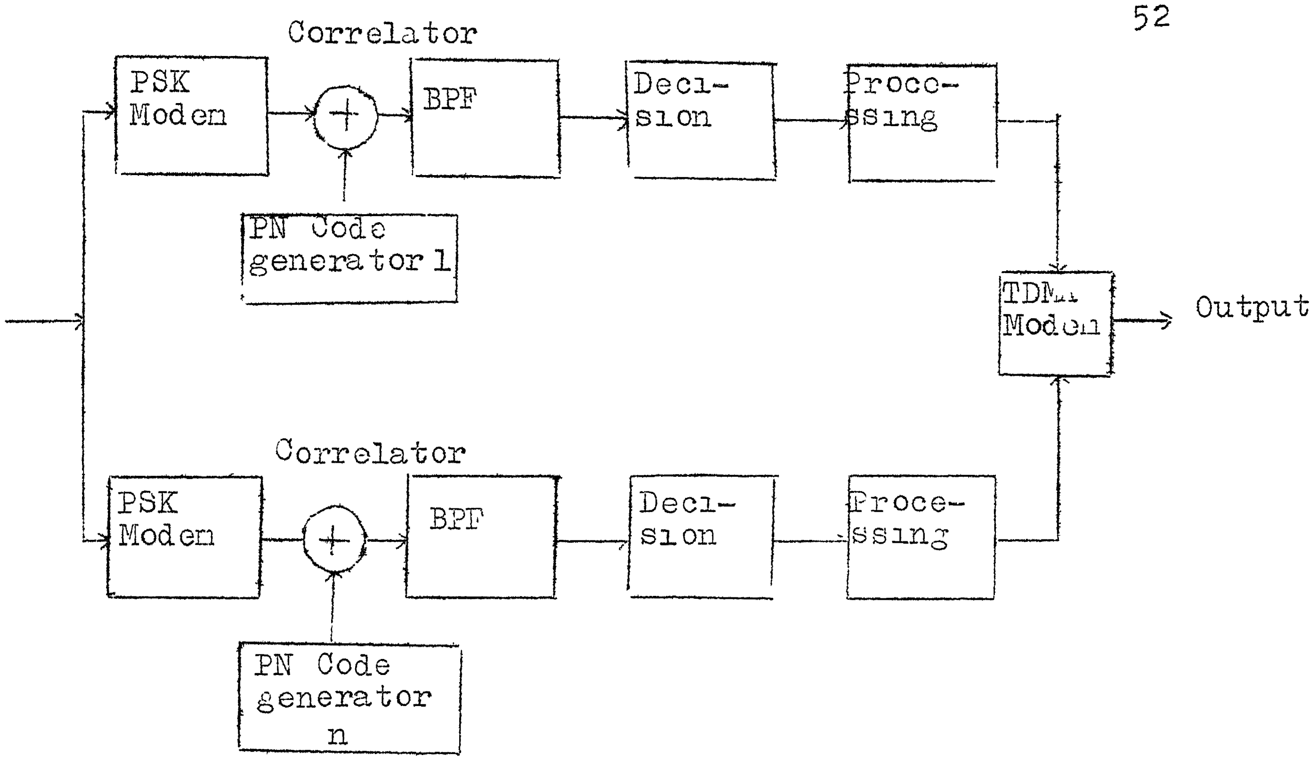


Fig. 4.7 Configuration for SSMA Uplink and TDMA Downlink

Since the carrier is coherent over all the bursts the dummy symbols for carrier recovery need not be sent in the preamble of each burst. Further if retiming is done onboard the communication efficiency will be further improved by reduction in the preamble time.

This is an attractive scheme because of the interference rejection capability of the uplink spread spectrum modulation and simplicity and all the advantages of TDMA on the downlink.

4.4 Hybrid Multiple Access Schemes

Now we will consider some hybrid multiple access schemes with onboard regeneration.

4.4.1 SS/TDMA uplink and TDMA downlink

Here we will consider a typical hybrid system, a combination of SSMA and TDMA for uplink. The signal is first transmitted through a SSMA modulator, where the messages acquire a widebandwidth due to the correlation operation with a PN sequence. The codes selected should be of equal length but distinct. Then this coded message is sent to the satellite using TDMA. In the satellite, the messages received from the various uplinks are demodulated using a TDMA demodulator and then time gated so that the signals from the various earth stations are sent to the respective SSMA demodulator for spread spectrum removal as shown in Fig. 4.8.

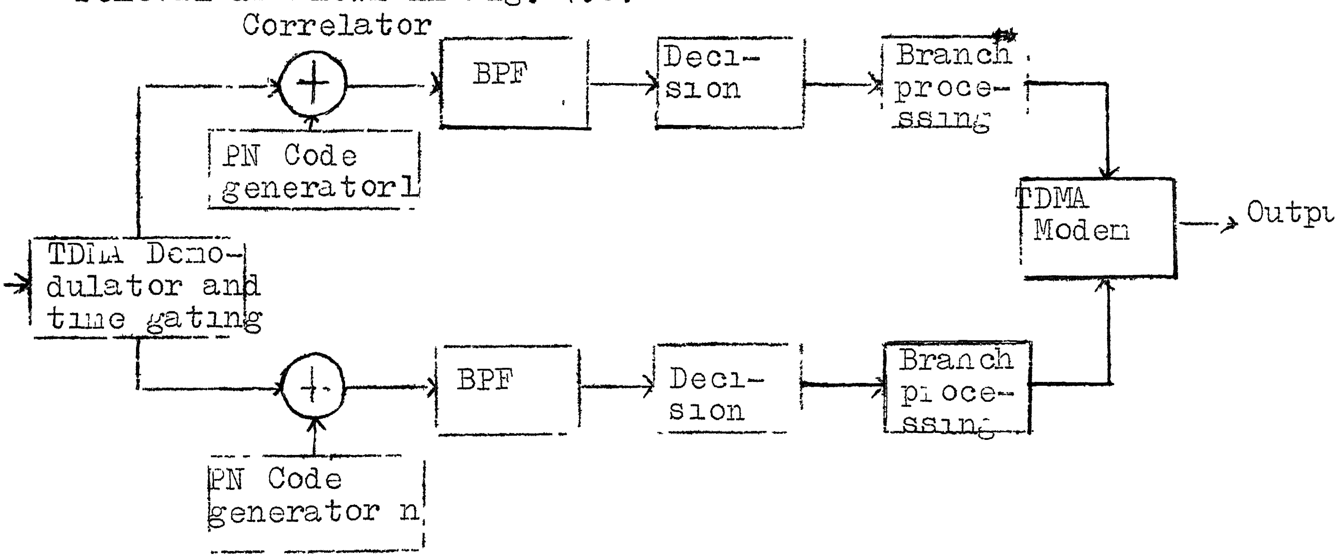


Fig. 4.8 SS/TDMA Uplink and TDMA Downlink

In this case only one signal is present at a time in the satellite and hence the cross-correlation noise due to the

simultaneous existence of various spread spectrum signals does not arise. Thus the uplink besides providing interference rejection also provides immunity from cross-correlation noise due to the multiple access. The downlink is sent on conventional TDMA. This modified TDMA system incorporating SSMA capability creates complex signal processing problems both at the satellite and at the earth station.

4.4.2 SS/FDMA Uplink and FDMA downlink

This scheme is useful for transmission of analog signals. In this case, each user is assigned the same PN code, but a different carrier frequency. The information to be sent is modulated on a carrier using frequency modulation and then spread with the help of a PN sequence. So the different stations use different carriers. The carrier spacing is done depending upon channel capacity as in the case of normal FDMA. So in the satellite repeater only one PN code generator is used to remove the spread spectrum modulation. The outputs are passed through various IF filters and then FM demodulation is done. The demodulated signal is further modulated as in the case of normal FDMA and sent downlink. The schematic for the onboard regenerator is as shown in Fig. 4.9.

The onboard regnerator is simpler in configuration and so also will be the ground receiver. But this system lacks in flexibility of reconfiguration as in the case of normal FDMA the added advantage being uplink interference rejection.

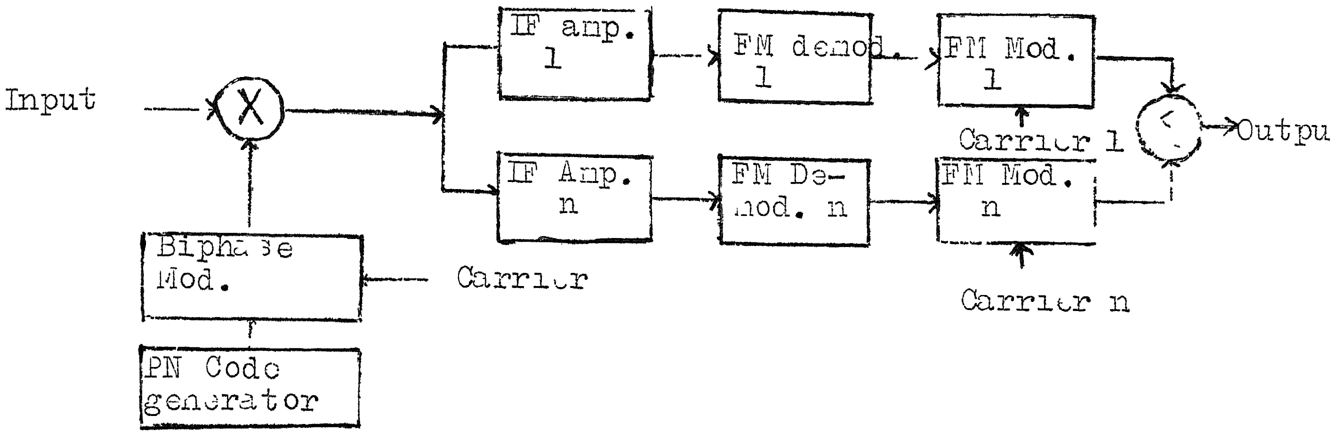


Fig. 4.9 SS/FDMA Uplink and FDMA Downlink

4.5 Selection of a Suitable Scheme for Military Requirements

The military requirements are different from the normal commercial communication requirements. The main differences are interference removal, antijamming capabilities and flexibility of operation. Further, many of the military users may be mobile tactical users away from the formation headquarters, who have to set up or dismantle the communication link fast and hence the simplicity of ground equipment may be an additional requirement. We have seen that a TDMA uplink does not provide antijamming facility and for this reason, an SSMA uplink is preferred. On the downlink if SSMA is employed the ground receiver will become complex. An FDMA downlink will not be flexible from the point of view of reconfiguration. Hence a TDMA downlink is preferred. The hybrid systems are attractive but make

the onboard and ground signal processing very complex. Hence a SSMA uplink and TDMA downlink is the most suitable choice to meet the requirements. A detailed schematic of the system is given in Chapter 6, which follows the power budget calculations presented in the next chapter.

CHAPTER 5

LINK BUDGET CALCULATION

In this chapter, we will calculate the power budget for the system selected, namely PCM/BPSK/SSMA uplink and PCM/BPSK/TDMA downlink.

5.1 Uplink Power Budget

For a reasonable good fidelity in the case of digital transmission of voice, 8 bit PCM is now accepted as a standard technique and hence sampling at 8 kHz gives a data rate of 64 Kbps. If there are 25 channels per earth station the data rate is 1.6 Mbps. If we use 13 dB processing gain (i.e. the code clock rate is 10 times the data rate) the transmitted data rate is 16 Mbps. The number of accessing stations we will arbitrarily take to be 60. The cross-correlation noise degradation is taken to be -2.8 dB [33].

From the simulation results the E_b/N_o to achieve an error rate of 10^{-4} is 4.4 dB. For two phase PSK, if the satellite repeater bandwidth is 40 MHz, the Inter Symbol Interference can be assumed to be 2 dB [4]. Due to imperfect phase extraction of the received carrier an effective signal loss of 0.5 dB can be assumed.

So the effective $E_b/N_o = 4.4 + 2.8 + 2 + 0.5 = 9.7$ dB.

The effective signal power received at the transponder

$C = E_b \cdot R \cdot$

where R is the bit rate of the received data.

Therefore, C/N_o at the transponder due to one accessing station $= 9.7 + 10 \log(\frac{16 \times 10^6}{60}) = 63.95$ dB Hz.

The received carrier to noise to noise power ratio at the satellite expressed in dB is given by

$\frac{C}{N_o}$ = Transmitter power (dBW) + Tx.Antenna gain(dB) - path loss(dB)

+ Boltzmann's constant (dB) + Satellite Receiving antenna gain (dB)

- Satellite Receiver Temperature (dB^{o}K)

Tx.Antenna gain (for a small mobile terminal)	= 37.5 dB
Path loss for uplink (6 GHz)	= 200.1 dB
Boltzmann's constant	= 228.6 dB
Satellite receiving antenna gain	= 26.5 dB
Satellite Receiver temperature	= 30 dB^{o}K

Therefore, Transmitter power = 63.95 - 62.5 = 1.45 dBW

5.2 Downlink Power Budget Calculation

The output of SSMA baseband demodulator is at a rate 1.6 Mbps. This is to be transmitted downlink in bursts. In TDMA to achieve 95 percent frame efficiency the gross data rate should be 1.68 Mbps. Since the carrier is coherent over all the bursts carrier recovery is not needed for each burst.

So the preamble of each burst need contain only clock recovery bits and unique word, besides the guard time. We will now calculate the frame length.

The frame efficiency is given as

$$\eta = 1 - \frac{T_{FS} + n(T_G + T_{BS})}{T_F}$$

where

T_{FS} is frame synchronisation length

n is number of stations accessing

T_G is guard time

T_{BS} is preamble length

T_F is frame length

Assuming guard time T_G of 1 bit, 16 bits for preamble T_{BS} and frame synchronization length T_{FS} of 20 bits

$$\eta = .95 = 1 - \frac{20 + 60 \times 17}{T_F}$$

$$T_F = 20.8 \text{ Kbits}$$

Taking a gross rate of 1.68 Mbps the frame duration is

1.2 msec.

For BPSK transmission to achieve an error rate of 10^{-4}, E_b/N_o required is 8.3 dB. Allowing 0.5 dB degradation due to imperfect carrier phase recovery effective E_b/N_o required is 8.8 dB.

Effective signal power received at the ground received

$$= E_b \times R$$

Therefore,

$$\frac{C}{N_o} = 8.8 + 10 \log(1.68 \times 10^6)$$

$$= \cancel{62.253}\ 71.053 \text{ dB Hz}$$

$$\frac{C}{N_o} = \text{Satellite EIRP (dB)} - \text{Path loss (dB)} - \text{Boltzmann's constant } (\text{dB}^\circ\text{K}) + (G/T) \text{ (dB)}$$

Path loss (4 GHz) = 196.6 dB

Boltzmann's constant = 228.6 dB

Ground station ~~frequency~~ figure of merit (G/T) = 17.5 $dB^\circ K$

Therefore Satellite EIRP = 71.053 - 49.5

= 21.55 dBW

To summarize, the power budget is as given in Table 5.1.

Table 5.1

Threshold Bit error rate 10^{-4}	
UPLINK BUDGET (6 GHz)	
Tx. Antenna gain	37.5 dB
Path loss	200.1 dB
Boltzmanns constant	228.6 dB
Satellite antenna (G/T)	- 3.5 dB
Carrier to noise ratio	65.95 dBHz
Ground transmitter power	1.45 dBW
DOWNLINK BUDGET (4 GHz)	
Carrier to noise ratio at ground receiver	62.253 dB Hz
Path loss	196.6 dB
Boltzmann's constant	228.6 dB
Ground station (G/T)	17.5 dB
Satellite EIRP	21.55 dBW

CHAPTER 6

CONCLUSIONS

We have seen that TDMA and SSMA are better suited accessing methods from a military communication point of view. Further SSMA has interference removal and random access capabilities. Thus we have concluded that SSMA uplink, onboard regeneration followed by downlink TDMA is an ideal scheme for military requirements. For spreading the spectrum we have considered the use of Direct Sequence only. For the military use, many of the ground terminals may be of mobile type which have to be assembled and made operational fast and have to be dismantled and moved away equally fast. In this context it is worthwhile considering the Emergency Communication Terminal (ECT) developed by ISRO for the STEP experiments. This terminal is mobile and airliftable. This has an antenna of 3M diameter and figure of merit (G/T) 17.5 dB/^{O}K. ISRO has reported that this terminal can be made operational within 6 hrs and was developed for analog voice link. But it can be adapted to military use and can be made operational in a lesser time. Because of these mobile considerations, this value of G/T of 17.5 dB/^{O}K has been adopted in the link budget calculations. The various segments of the system, namely ground transmitter, satellite transponder and ground receiver of a typical military link selected, are explained in the following paragraphs.

To spread the spectrum of the information bearing signal we have used a maximal length sequence of length 2047 bits generated by a shift register of 11 stages. This shift register is capable of generating 176 distinct maximal length sequences [See Appendix A]. So the potential number of users is 176 but we have restricted the number of simultaneous users to 60. As mentioned in Section 5.1 the data rate of each accessing station is 1.6 Mbps (64 Kbps per voice source and 25 users per channel). The spreading of the signal depends upon the code clock rate. Here we have assumed a processing gain of 13 dB i.e. the code clock rate is 32 MHz and the ground transmitter power required has been calculated as 1.45 dBW.

Though the spreading is dependent upon the code clock rate, a code of shortlength should not be selected because the randomness of the signal will depend upon the length of the code as seen from eqn. 2.5. Based on these, the configuration of the ground transmitter would appear as shown in Fig. 6.1.

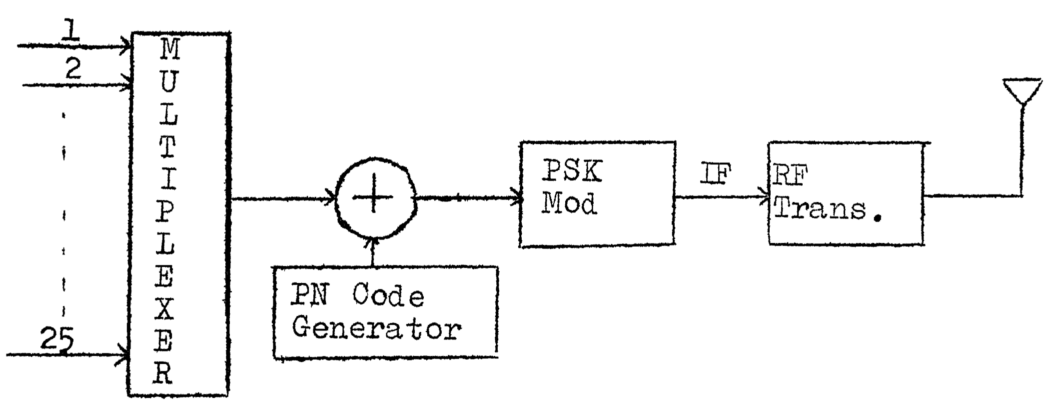


Fig. 6.1 Ground Transmitter

In the satellite section, the SSMA signal is converted into baseband and is sent downlink in bursts. With the data rates and framelength as given in Section 5.2 one needs a large size buffer at the satellite. This problem can be overcome by either increasing the downlink rate or using demand assigned TDMA or decreasing the frame length. But decreasing the frame length will affect the frame efficiency. If the downlink data rate is increased the ground receiver will become more complex. The demand assignment will require a central controlling facility at the satellite itself. So the block diagram of the signal processing part of the satellite transponder is as shown in Fig. 6.2.

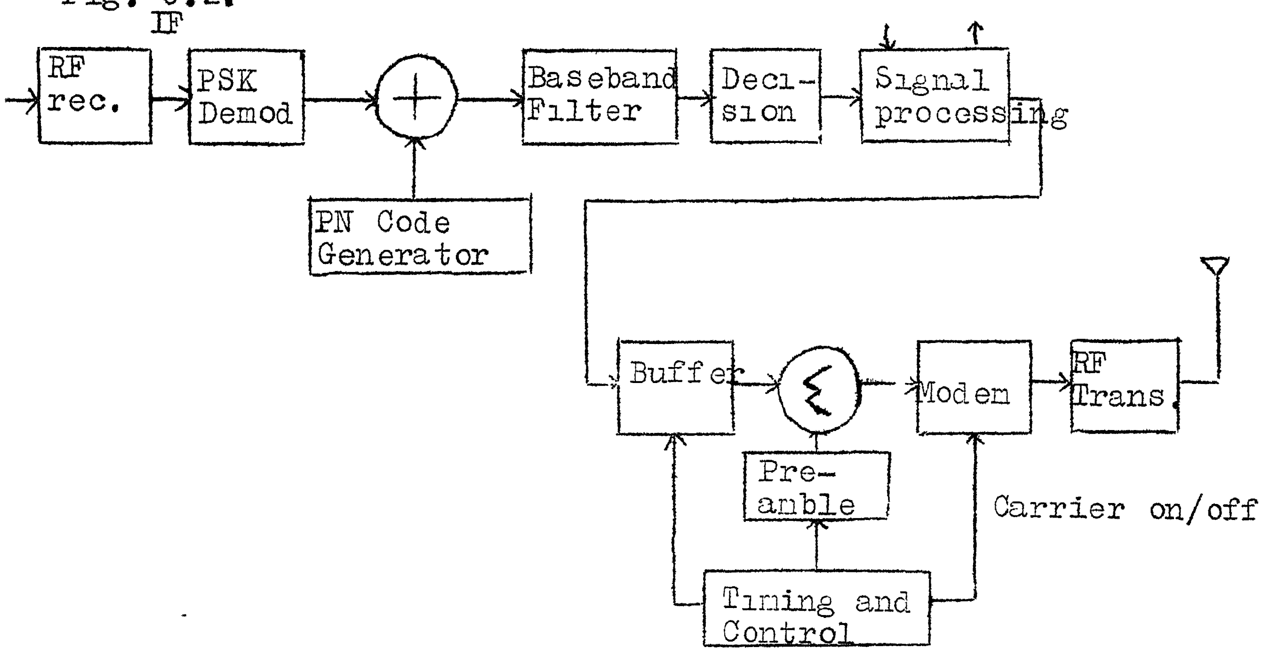


Fig. 6.2 Satellite Transponder

The timing and control decides when the buffer output is to be mixed with the preamble and transmitted.

At the ground receiver as shown in Fig. 6.3 the received signal is converted into IF and donodulated in the PSK demodulator. The unique word is detected in the unique word detector. Controlled by the timing control, the information meant for the particular receiver is read into the buffer. The output is sent to the demultiplexer which separates out the various users.

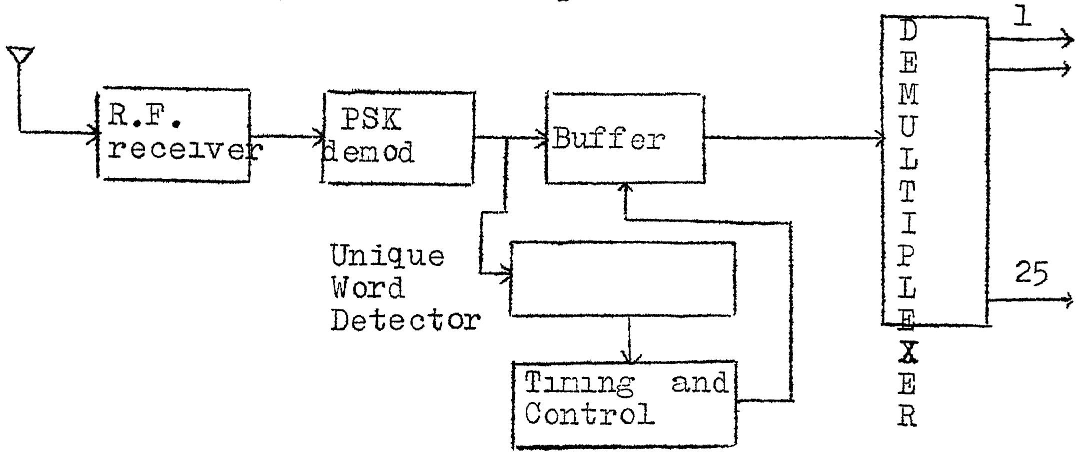


Fig. 6.3 Ground Receiver

The buffer requirements in the satellite transponder can be investigated further. One of the important aspects of the SSMA is code synchronization. In the simulation used here, we have assumed proper synchronization. The degradation caused by improper synchronization is to be studied further. Also the performance of Frequency Hopping vis-a-vis Direct sequence is an area of further interest.

SCPC	Single-carrier-per-channel. Used with demand assigned systems.
SSMA	Spread spectrum multiple access. Each accessing station uses a different code for spreading the spectrum.
TDMA	Time division multiple access. Accessing stations are separated in time.
SS/TDMA	Spread spectrum TDMA a hybrid technique.
SS/FDMA	Spread spectrum FDMA a hybrid technique.

REFERENCES

[1] K. KOGA, T. MURATANI and A. OGAWA, 'On-Board Regnerative Repeaters Applied to Digital Satellite Communications', Proc. IEEE, Vol. 65, No.3, March 1977.

[2] 'Communications Satellite Systems' Edited by R.G. GOULD and Y.F. LUM, IEEE Press, 1975.

[3] O.N. CALLA and JOHN FRANCIS, 'Step in General', Paper presented in the seminar on 'Step Experiances' held at SAC Ahmedabad from Mar. 19-20, 1979.

[4] B. PRASADA, RAJENDRA KUMAR and V. SINHA, 'Multiple accessing on Indian National Satellite', Technical Report TR-24-1974, August 1974, I.I.T. Kanpur.

[5] T. MURATANI, 'Satellite switched time-domain multiple access' in EASCON 1974, Washington, D.C. pp. 189-196.

[6] M. YASUHIKO ITO, URANO, T. MURATANI, M. YAMAGUCHI 'Analysis of a switch matrix for an SS/TDMA system', Proc. IEEE, Vol. 65, No.3, March 1977.

[7] R.W. KREUTEL, Jr. D.F. DIFONZO, W.J. ENGLISH, and R.W. GRUNER, 'Antenna technology for frequency reuse satellite communications', Proc. IEEE, Vol. 65, No.3, March 1977.

[8] P.J. BARTHOLOME, 'Propogation experiments at 11/14 GHz as part of the European communications satellite program' Proc. IEEE Vol. 65, No.3, March 1977.

[9] R.K. CRANE, 'Prediction of the effects of rain on satellite Communication systems', Proc. IEEE, Vol. 65, No.3, March 1977.

[10] D. REUDINK, 'A digital 11/14 GHz multibeam switched satellite systems', Presented at the AIAA/CASI 6th communication satellite system Conf. Paper 76-225 Montreal, April 1976.

[11] R.J. WESTCOTT, 'Investigation of multiple FM/FDM carrier through a satellite TWT operating near to saturation' Proc. IEEE June 1967.

[12] L.H. WILSON, 'Optimum design of FM satellite links', Proc. IEEE International Communications Conf. Boulder, Colorado, June 1969.

[13] P.L. BARGELLINI and W.G. SCHMIDT, 'Digital communications via satellites: Advantages and trends', EASCON '70-203.

[14] M.P. RISTENBATT, J.L. DAWS. Jr. 'Performance criteria for spread spectrum communications', IEEE Trans. Commun. Vol. COM-25, No.8, August 1977.

[15] J. WITTMAN, 'Categorization of multiple access/random access modulation techniques', IEEE Trans. Commun. October, 1967.

[16] A.M. WERTH, 'Spade: A PCM FDMA demand assignment system for satellite communications', Proc. INTELSAT/IEE Int. Conference on digital satellite communications, 1969.

[17] R.M. HULTBERG, F.H. JEAN, M.E. JONES, 'Time division access for military communication satellites', IEEE Trans. AES, Vol. AES-1, No.3, Dec. 65.

[18] T. SEKIMOTO, and J.G. PUENTE, 'A satellite time-division multiple-access experiment', IEEE Trans. Commun. Vol. COM-16, No.4, August, 1968.

[19] W. SCHREMPP and T. SEKIMOTO, 'Unique word detection in digital burst communications', IEEE Trans. Commun. Vol. 16, No.4, August 1968.

[20] Y. INOUE, 'Design of acquisition system for PCM-TDMA satellite communication system', Electronics and Communication in Japan, Vol. 53-B, No.5, 1971.

[21] G. ECKHARDT, B. REIDEL and H. RUPP, 'Results of German TDMA experiments', Presented at AIAA 4th communications satellite systems conference Washington, D.C./April, 1972.

[22] O.G. GABBARD, 'Design of a satellite time-division multiple-access burst synchronizer', IEEE Trans. Com. Tech., Vol. Com-16, No.4, August 1968.

[23] N.C. Mohanty, 'Spread spectrum and time division multiple access satellite communications', IEEE Trans. Commun. Vol. Com-25, No.8, August 1977.

[24] J.H. WITTMANN, 'Analysis of a hybrid frequency-time hoping random access satellite communication system', IEEE International Convention Record, March 1967.

[25] H.H. SCHREIBER, 'Self-noise of frequency hopping signals', IEEE Trans. Commun. Technol. Vol. Com-17, Oct. 1969.

[26] J. BURNSWEIG and J. WOOLDRIDGE, 'Ranging and data transmission using digital encoded FM-Chirp', Surface acoustic wave filters', IEEE Trans. MTT. April, 1973.

[27] W.F. UTLAUT, 'Spread spectrum - principles and possible application to spectrum utilization and allocation', ITU telecommunication journal, Vol. 45, Jan. 1978.

[28] R.C. DIXON, 'Spread spectrum systems', John Wiley and Sons, 1976.

[29] TAUB and SCHILLING, 'Principles of communication systems', McGraw-Hill Kogakusha Ltd., 1971.

[30] LINDSEY and SIMON, 'Telecommunication system engineering', Prentice-Hall Inc. 1973.

[31] W.W. PETERSON, 'Error correcting codes', MIT Press, Wiley, New York, 1961.

[32] K. KOGA, T. MURATANI, A. OGAWA, M. YAMAGUCHI and K. NOSAKA, 'A satellite regenerative repeating system using higher order DPSK', Trans. IECE (Japan), 1976.

[33] H.J. KOCHEVAR, 'Spread spectrum multiple access communications experiment through a satellite', IEEE Trans. Commun. Vol. COM-25, No.8, August, 1977.

BIBLIOGRAPHY

[1] P.L. Bargellini and W.G. Schmidt, 'Digital communication via satellite: Advantages and Trends, EASCON 70-203.

[2] W.E. Bradley, 'Communications strategy of geostationary orbit', Astronaut, Aeronaut, Vol. 6, No.4, Apr. 1968.

[3] J.V. Charyk, 'Potentials of digital satellite communications', An address before the intelsat/IEE International Conference on digital satellite communications, LONDON, Nov. 69.

[4] D.I. Dalgleish and A.K. Jefferis, 'Some orbits for communications satellite systems affording multiple access', Proc. Inst. Elec. Eng. Vol. 112, Jan. 1965.

[5] R.S. Davies and J.M. Stephenson, 'A communication satellite system for many users', AIAA, Communication Satellite Systems Conference, Washington, D.C. 1966.

[6] J.C. Fuenzalida, 'A comparative study of the utilization of the geostationary orbit', Proc. Intesat/IEE Conf. Digital Satellite Communication, Nov. 1969.

[7] A.F. Ghais, J.R. Alper and J. Oslund, 'Transoceanic Telecommunications via satellite', Telecommunications Vol. 13, No.5, May 1979.

[8] J.K.S. Jowett and A.K. Jefferis, 'Ultimate communications capacity of the geostationary - satellite', Proc. INST. Elec. Engg., Vol. 116, August 1969.

[9] E.J. Martin, W.S. Mckee, 'Commercial satellite communications experiance', IEEE Spectrum, Vol. 4, No.7, July 1967.

10] W.L. Pritchard, 'Satellite communication - An overview of the problems and programs', Proc. IEEE Vol. 65, No.3, Mar 1977.

11] H.E. Rowe and A.A. Penzias, 'Efficient spacing of synchronous communication - satellites', Bell Syst. Tech. J., Vol. 47, No. 10, Dec. 1968.

12] J. Salomon, 'Satellite communications systems', Telecommunications, Vol. 13, No.5, May 1979.

13] S. Topol, 'Satellite communications, History and future', Microwave Journal, Nov. 1978.

14] D.J. Withers, 'Effective utilization of the geostationary orbit for satellite communications', Proc. IEEE, Vol. 65, No.3, Mar. 77.

15] J.M. Aein, 'Multiple access to a hard-limiting communication - satellite repeater', IEEE Trans. Space Electron. Telem., Vol. SET-10, pp 159-167, 1964.

16] D.R. Anderson and P.A. Wintz, 'Analysis of a spread spectrum multiple-access system with a hard limiter', IEEE Trans. Commun. Technol. Vol. COM-17, Apr. 69.

17] H. Blasbalg, H.F. Najjar, R.A. d'Antonio and R.A. Haddad, 'Air-ground, ground-Air communications using psuedo-noise through a satellite', IEEE Trans. Aerosp. Electron Syst., Vol. AES-4, Sep. 68.

18] C.R. Cahn, 'Spread spectrum applications and state-of-the art equipments', Magnavox Communications and Navigation, Torrance, California, Jan. 1973.

19] D.E. Carter, 'On generation of psuedo noise codes', IEEE Trans. Aerospace Elect. Syst., Vol. AES-10, Nov. 1974.

20] N.B. Chakrabarti and M. Tomlinson, 'Design of sequences with specified autocorrelation and crosscorrelation', IEEE Trans. Commun. Vol. COM-24, No. 11, Nov. 1976.

21] R.C. Dixon, 'Spread spectrum systems', Newyork, Wiley, 1975.

22] P.R. Drouilhet, Jr. and S.L. Bernstein, 'TATS - A band spread demodulation system for multiple access tactical satellite communication' in IEEE EASCON 69, Conv. Rec., pp. 126-132.

23] H.J. Freiedman, 'Jamming susceptibility', IEEE Trans. Aerospace Elect. Sys. July 68.

24] E.I.N. Gilbert, 'Optimum binary sequences for spread spectrum multiplexing', IEEE Trans. Inf. The., July 1963.

25] R. Gold, 'Optimal binary sequences for spread spectrum multiplexing', IEEE Trans. Inform. Theory, Vol. IT-13, Oct. 1967.

26] P.M. Hopkins, R.S. Simpson, 'Probability of error in psuedo noise modulated spread spectrum binary communication systems', IEEE Trans. Commun., Vol. COM-23, No.4, Apr 1975.

[27] J.J. Jones, 'Hard limiting of two signals in random noise', IEEE Trans. Inf. The., Jan. 1963.

[28] E.L. Key, 'An analysis of the structure and complexity of nonlinear binary sequence generators', IEEE Trans. Inf. The., Nov. 1976.

[29] H.J. Kochevar, 'Spread spectrum multiple access communications experiment through a satellite', IEEE Trans. Commun. Vol. COM-25, No.8, Aug. 77.

[30] I. Kadar and H.H. Schreiber, 'Performance of spread spectrum systems in a multipath environment', WESCON, 1970.

[31] J.H. Lindholm, 'An analysis of the pseudo-randomness properties of sub-sequences of long m-sequences', IEEE Trans. Inf. Theory, July 1968.

[32] R.J. Martel, 'Determination of crosscorrelation noise for a psuedo-noise multiple access communication system', Westing house SMS technical memorandum, No.1, August 1969.

[33] R.J. Martel, 'System design considerations for a satellite spread-spectrum random access communication experiment', Westinghouse ATS system Technical memorandum No.2, June 68.

[34] N.C. Mohanty, 'Spread spectrum and time division multiple access satellite communications', IEEE Trans. Commun. Vol. COM-25, No.8, Aug. 1977.

[35] M.P. Rishenbatt, J.L. Daws, Jr., 'Performance criteria for spread spectrum communications', IEEE Trans. Commun. Vol. COM-25, No.8, Aug. 1977.

[36] M.P. Ristenbatt, J.L. Daws, Jr., and H.M. Pearce, 'Crack resistant sequences for data security', IEEE National Telecommunications Conference Record, Vol. 1, Nov. 1973.

[37] J.R. Sergo, Jr. and J.F. Hayes, 'Analysis and simulation of a PN synchronization system', IEEE Trans. Commun. Technol. Vol. COM-18, pp. 676-679, 1970.

[38] H.H. Schreiber, 'Self noise of frequency hopping signals', IEEE Trans. Commun. Technol., Vol. COM-17, Oct. 1969.

[39] R.A. Scholtz, 'The spread spectrum concept', IEEE Trans. Comm. Vol. COM-25, No.8, Aug. 1977.

[40] W.F. Utlaut, 'Spread spectrum-principles and applications to spectrum utilization and allocation', ITU Telecommunication Journal, Vol. 45, Jan. 1966.

[41] R.B. Ward, 'Digital communications on a psuedo-noise tracking link using sequence inversion modulation', IEEE Trans. Commun. Technol. Vol. COM-15, Feb. 1967.

[42] L.E. Zegers, 'Common bandwidth transmission of information signals and pseudonoise synchronization waveforms', IEEE Trans. Commun. Technol., Dec. 1968.

[43] 'ATS spread spectrum experiment', Final report, Contract NAS 5-21598, Jan. 1972.

[44] 'Proceedings of the 1973 symposium on spread spectrum communications', Naval Electronics Laboratory Centre, SanDiego, California, Mar. 1973.

[45] 'Spread spectrum communications', AGARD Lecture series No. 58, National Technical Information Service, AD-766-914, July 1973.

Time Division Multiple Access

[46] E. Bachmann, K.G. Howe and T.J. Petry, 'Introduction of digital transmission including TDMA/DSI as viewed by a communications organization' in Intelsat/IECE/ITE 3rd Int. Conf. Digital Satellite Commun., 1975 Kyoto, Japan.

[47] C.R. Carter and S.S. Haykin, 'Precision synchronization to a switching satellite using PSK signals' in Int. Conf. Commun., 1974, Minneapolis.

[48] R. deBuda, 'Synchronization for time-division multiple-access experiments', Canadian General Electric Tech. Infrm. Ser., RQ72EE4, June 1972.

[49] J. Deal and J. Buegler, 'A demand-assigned, time-division multiple-access system for military tactical application', presented at the AIAA/CASI, 6th Commun. Satellite System Conf., Apr. 1976.

[50] G. Dill, J. Deal and W. Mailett, 'Intelsat prototype TDMA system', presented at IEEE Intercon., Geneva, 1975.

[51] S.E. Dinwiddy, 'A simple TDMA system for satellite data communication networks' in Intelsat/IECE/ITE, 3rd Int. Conf. Digital Satellite Commun., 1975, Kyoto, Japan.

[52] B. Ekstroem, 'Optimized UW detection for TDMA communications', in Intelsat/IECE/ITE, 3rd Int. Conf. Digital Satellite Commun., 1975, Kyoto, Japan.

[53] W.G. Geddes, 'Digital satellite communications in the Intelsat system - past, present, and future', presented at Intelsat/IECE/ITE, Int. Conf. Digital Satellite ICDSC-3, Special address, Kyoto, Japan, 1975.

[54] O.G. Gabbard, 'Design of a satellite time-division multiple-access, burst synchronizer', IEEE Trans. Commun. Technol. Vol. COM-16, Aug. 1968.

[55] O.G. Gabbard and P. Kaul, 'Time-division multiple access' EASCON, 1974, Washington, D.C.

[56] O.G. Gabbard, P. Kaul, A. Walker, J. Hangen and Pradeep Kaul, 'The common TDMA terminal for the Telesat TDMA system', in Int. Conf. Commun., 1975, Sanfrancisco.

[57] O.G. Gabbard and P. Kaul, 'A cost effective TDMA system for domestic applications', in Intelsat/IECE/ITE, 3rd Int. Conf. Digital satellite commun., Kyoto, Japan, 1975.

[58] F.M. Gardner, 'Comparison of QPSK carrier regenerator circuits for TDMA application', in Int. Conf. Commun. Minneapolis, 1974.

[59] H. Ganssmantel and B. Ekstrom, 'TDMA synchronization for future multi-transponder satellite communications', in Int. Conf. Commun., 1974 Minneapolis.

[60] J. Husted, A. Walker, and G. Goubeand, 'A time-division multiple-access system for the defense satellite communications system' in EASCON, 1970.

[61] Y. Inoue, 'Acquisition in TDMA satellite communications system - SMAX', Rev. Elec. Commun. Lab., Vol. 17, Aug. 1960.

[62] Y. Inoue, 'Design of acquisition system for a PCM-TDMA satellite communication system', Electron. Commun. Japan, Vol. 53, May 1970.

[63] I.M. Jacobs, 'Configuring a TDMA satellite communication system with coding', presented at Proc. of 5th Int. Conf. on Syst. Science, Honolulu, Jan. 1972.

[64] D. Jarett, 'A baseline domestic communications satellite system for the 1980's' presented at AIAA/CASI, 6th Commun. Satellite Syst. Conf. Montreal, Apr. 1976.

[65] P. Kaul, 'An all-digital variable threshold codeword correlator', in Intelsat/SEE, 2nd Int. Conf. Digital Satellite Commun., Paris, 1972.

[66] S. Kondo, 'Clock synchronization in TDMA satellite communication system - SMAX', Rev. Elec. Commun. Lab., Vol. 17, No.8, Aug. 1969.

[67] S. Kondo, K. Hirda, and M. Kuramoto, 'Design of clock phase-lock loop for PCM-TDMA satellite communication system', Electron. Comm. Japan, Vol. 53, May 1970.

[68] R.K. Kwan, 'A TDMA application in the Telesat satellite system', in Nat. Telecomm. Conf., Atlanta, 1973.

[69] R.K. Kwan, 'The Telesat TDMA system', in Int. Conf. Commun. San Francisco, 1975.

[70] R.K. Kwan, 'The telesat TDMA field trial', in INTELSAT/IECE/ITE, 3rd Int. Conf. Digital satellite commun., Kyoto, Japan 1975.

[71] H. Kaneko, Y. Katagiri, and T. Okada, 'The design of a PCM mastergroup codec for the Telesat TDMA system', in Int. Conf. Commun. San Francisco, 1975.

[72] D. Lombard, G. Payet, H. Herr and M. Pruskil, 'The TDMA system and test program for field trial via symphonie', in INTELSAT/SEE, 2nd Int. Conf. Digital satellite commun., 1972 Paris.

[73] L. Lundquist, M. Lopriore and F. Gardner, 'Transmission of 4Q-PSK TDMA over satellite channels', IEEE Trans. Commun. Tech., COM-22, Sept. 1974.

[74] W.G. Maillet, 'Processing of bursts in a TDMA system', in Intelsat/IEE, Int. Conf. Digital satellite commun., London, 1969.

[75] W.G. Maillet, 'Intelsat's 50 Mb/s TDMA-2 system', in INTELSAT/SEE, 2nd Int. Conf. Digital Satellite Commun. Paris 1972.

[76] I. Matsushita, Y. Tsuji, and Y. Sohme, 'Applications of error-correcting codes to TDMA satellite' Int. Conf. Commun., Satt. 1973.

[77] T. Muratani, 'Satellite-switched time-domain multiple access', in EASCON, 1974, Washington, D.C.

[78] K. Nosaka, H. Sasaki, K. Amano, and H. Michishita, 'TTT system (50 Mb/s PCM-TDMA system with time-preassignment and TASI) and its satellite test results', IEEE Trans. Commun. Technol., Vol. COM-20, Aug. 1972.

[79] P.P. Nuspl, 'Proposed experiments in regional TDMA with demand assignment', in INTELSAT/SEE, 2nd Int. Conf. Digital Satellite Commun. Paris 1972.

[80] P.P. Nupsl, N.G. Davies, and R.L. Olsen, 'Ranging and synchronization accuracies in a regional TDMA experiment' in INTELSAT/IECE/ITE, 3rd Int. Conf. Digital satellite commun,, Kyoto, Japan 1975.

[81] P.P. Nupsl and K.E. Brown, 'TDMA bibliography - 1976' Commun Res. Centre, rep.,

[82] A. Ogawa, Y. Hirata, M. Ohkawa, and H. Saitoh, 'A TDMA terminal for the spotbeam satellite and its field test results' in Int. Conf. Commun. Minneapolis 1974.

[83] L. Palmer and S. Rhodes, 'A comparison of independent burst and burst coherent TDMA techniques', in INTELSAT/O IEE, Int. Conf. Digital Satellite Commun., London, 1969.

[84] B. Reidel, M. Rathgeber, and J. Zilg, 'The initial acquisition unit of the French/German TDMA system for INTELSAT application', in INTELSAT/IECE/ITE, 3rd Int. Conf. Digital Satellite Commun., Kyoto, Japan, 1975.

[85] J. Ramasastry, S. Verma, and V. Volteras, 'Transmission techniques for western union domestic satellite communication system', presented at AIAA/CASI, 6th Commun. Satellite Systems Conf., Montreal, Apr. 1976.

[86] U. Reiner and J. Zilg, 'Reflections and proposals concerning the solution of TDMA - typical measuring and s supervision problems', in INTELSAT/SEE, 2nd Int. Conf. Digital Satellite Commun., Paris 1972.

[87] W.G. Schmidt, 'Satellite time-division multiple-access systems: past, present and future', Telecommun. Aug. 1973.

[88] W.G. Schmidt, O.G. Gabbard, E.R. Cacciamani, W.G. Maillet and W.W. Wu, 'MAT-1 : Intelsat's experimental 700-channel 700-channel TDMA/DA system', in Intelsat/IEE, Int. Conf. Digital Satellite Commun., London 1969.

[89] W.G. Schmidt, 'The application of TDMA to the Intelsat IV satellite series', COMSAT Tech. Rev., Vol. 3, 1973.

[90] H. Sasaki, T. Maruyama, M. Hashimoto, H. Kanzaki and Y. Sakamoto, 'Burst synchronization in TDMA system', in Intelsat/IEE, Int. Conf. Digital Satellite Commun., London 1969.

[91] W. Schrempp and T. Sekimoto, 'Unique word detection in digital burst communications', IEEE Trans. Commun. Technol., Vol. COM-16, Aug. 1968.

[92] H. Kurihara, A. Ogawa, and Y. Hirata, 'A new initial acquisition technique for PCM-TDMA satellite communication system' in INTELSAT/IECE/ITE, 3rd Int. Conf. Digital Satellite Commun., 1975 Kyoto, Japan.

[93] Y. Suguri, H. Doi and E. Metzzer, 'A TDMA/PCM experiment on applications technology satellites', IEEE Trans. Commun. Technol., Vol. COM-19, Apr, 1971.

[94] M. Takada, S. Nakamura, S. Kondo, Y. Inoue, M. Ono, and H. Ikeda, 'New PCM-TDMA satellite communication system and variable destination channel control techniques', in INTELSAT/IEE, Int. Conf. Digital satellite Commun., London, 1969.

[95] J. Wittman, 'Categorization of multiple-access/random-access modulation techniques', IEEE Trans. Commun. Oct. 76.

[96] Y. Watanabe and K. Izumi, 'A new TDMA system for domestic service and its high-speed PSK modem', in INTELSAT/IECE/ITE, 3rd Int. Conf. Digital Satellite Commun., Kyoto, Japan 1975.

[97] D.E. White, 'A new synchronization scheme for satellite TDMA systems' in INTELSAT/IECE/ITE, 3rd Int. Conf. Digital satellite commun., Kyoto, Japan, 1975.

[98] D.J. Withers and A.K. Jefferis, 'A TDMA system for Intelsat' in AIAA, 4th Commun. Satellite Syst. Conf., 1972.

[99] S. Yokoyama, K. Kato, T. Noguchi, N. Kusama, and S. Otani, 'The design of a PSK modem for TELESAT TDMA system', in Conf. Rec. Int. Conf. Commun., Sanfrancisco, 1975.

[100] 'TDMA system synchronization through a global beam transponder', in Nat. Telecommunications Conf., Atlanta, 1973.

APPENDIX A

PROPERTIES OF MAXIMAL SEQUENCES

Maximal codes are the longest codes that can be generated by a shift register of a given length. In binary shift register sequence generators, the maximum length sequence is 2^n-1, where n is the number of stages in the shift register. Properties of maximal sequences are briefly as follows :

i) Balance property :- The number of ones in a sequence differs from the number of zeros by atmost one bit. This causes the DC component in a code or code modulated signal to be neglected.

ii) Run property :- The statistical distribution of ones and zeros is well defined and always the same, but the relative position of runs vary from code to code. There are exactly $2^{n-(p+2)}$ runs of length p for both ones and zeros in every maximal sequence. (Except that there is only one run containing n ones and one containing n-1 zeros). A run is defined as a series of ones or zeros grouped consecutively.

iii) Correlation property :- Auto-correlation value of a maximal linear code is such that for all values of phase shift the correlation value is -1, except for the 0 $\pm$ 1 bit phase shift area, in which correlation varies linearly from the -1 value to 2^n-1.

iv) Generic property :- A modulo-2 addition of a maximal-length linear code with a phase shifted version of itself results in another replica with a phase shift different from either of the replicas.

v) Every possible state, except all-zeros state, or n-tuple of a given n-stage generator exists at sometime during the generation of a complete code cycle,

Using all of the possible linear combinations of feedback taps for an n-stage register, there are $[\varphi(2^n-1)]/n$ maximal linear sequences that can be generated. Here $\varphi(2^n-1)$ is an Euler number, the number of positive integers including 1 that are relatively prime to and less than 2^n-1. Table A-1 shows the number of maximal sequences that can be generated with some shift registers of length n.

Table A-1

Total register length n	Total number of sequences $[\varphi(2^n-1)]/n$	Sequence length $2^n - 1$
4	2	15
5	6	31
6	6	63
7	18	127
8	16	255
9	48	511
10	60	1023
11	176	2047
12	144	4095

APPENDIX B


```
        BPSK/TDMA TRANSMISSION
        INTEGER DATA(5000),ERROR,TOTBIT,DDATA(5000)
        DIMENSION A(5001),GAUSS(5000)
        OPEN(UNIT=60,FILE='PSK.DAT')
        IU=61
        OPEN(UNIT=IU,FILE='PSK.OUT')
        ERROR=0
        READ(60,*)SIGMA
        READ(60,*)PYE
        READ(60,*)IL
        DO 115 KL=1,IL
C.......................................................................
C       DATA GENERATION
C.......................................................................
        DO 100 I=1,5001
100     A(I)=RAN(DUM)
        DO 101 I=1,5000
        DATA(I)=0
101     IF(A(I).GE..5)DATA(I)=1
        DO 102 I=1,5000
C.......................................................................
C       NOISE SAMPLE GENERATION
C.......................................................................
        ZG1=A(I)
        ZG2=PYE*A(I+1)
        ZG1=-2.*ALOG(ZG1)
        ZG1=SQRT(ZG1)
        ZG2=COS(ZG2)
102     GAUSS(I)=ZG1*ZG2*SIGMA
C.......................................................................
C       CHANNEL TRANSMISSION AND DETECTION
C.......................................................................
        DO 112 I=1,5000
        IF(DATA(I).EQ.0.AND.GAUSS(I).GT.1.OR.DATA(I).EQ.1.AND.
        1GAUSS(I).LT.-1)ERROR=ERROR+1
112     CONTINUE
115     CONTINUE
        TOTBIT=IL*5000
        ATOT=TOTBIT:BER=ERROR/ATOT
        TYPE 22,ERROR,TOTBIT,SIGMA,BER
        WRITE (IU,22)ERROR,TOTBIT,SIGMA,BER
22      FORMAT(5X,'NO OF ERRORS=',I6/5X,'TOTAL
        1 NO. OF BITS=',I7/5X,'SIGMA=',E15.8/5X,'BER=',E15.8)
        CLOSE(UNIT=60)
        CLOSE(UNIT=IU)
```

```
      DPSK/TDMA TRANSMISSION
      INTEGER DATA(5000),ERROR,TOTBIT,DDATA(5000),DCDATA(5001)
      DIMENSION A(5001),GAUSS(5000)
      OPEN(UNIT=60,FILE='PSK.DAT')
      IU=61
      OPEN(UNIT=IU,FILE='PSK.OUT')
      ERROR=0
      READ(60,*)SIGMA
      READ(60,*)PYE
      READ(60,*)IL
      DO 115 KL=1,IL
C.......................................................................
C     DATA GENERATION
C.......................................................................
      DO 100 I=1,5001
100   A(I)=RAN(DUM)
      DO 101 I=1,5000
      DATA(I)=0
101   IF(A(I).GE..5)DATA(I)=1
C.......................................................................
C     NOISE SAMPLE GENERATION
C.......................................................................
      DO 102 I=1,5000
      ZG1=A(I)
      ZG2=PYE*A(I+1)
      ZG1=-2.*ALOG(ZG1)
      ZG1=SQRT(ZG1)
      ZG2=COS(ZG2)
102   GAUSS(I)=ZG1*ZG2*SIGMA
C.......................................................................
C     DIFFERENTIAL ENCODING
C.......................................................................
      DCDATA(1)=1
      DO 120 I=1,5000
      IF(DCDATA(I).EQ.0)GO TO 121
      DCDATA(I+1)=DATA(I)
      GO TO 120
121   DCDATA(I+1)=DATA(I)+1
      IF(DCDATA(I+1).EQ.2)DCDATA(I+1)=0
120   CONTINUE
C.......................................................................
C     CHANNEL TRANSMISSION
C.......................................................................
      DO 112 I=1,5000
      IF(DCDATA(I).EQ.0.AND.GAUSS(I).GT.1.OR.DCDATA(I).EQ.1.AND.
```

```
      1GAUSS(I).LT.-1)DCDATA(I)=DCDATA(I)+1
      IF(DCDATA(I).EQ.2)DCDATA(I)=0
112   CONTINUE.
C.....................................................................
C     DIFFERENTIAL DECODING
C.....................................................................
      DO 125 I=2,5001
      IF(DCDATA(I).EQ.0.AND.DCDATA(I-1).EQ.0)GO TO 126
      DDATA(I)=DCDATA(I)*DCDATA(I-1)
      GO TO 125
126   DDATA(I)=1
125   CONTINUE
      DO 127 I=2,5001
127   IF(DDATA(I).NE.DATA(I-1))ERROR=ERROR+1
115   CONTINUE
      TOTBIT=IL*5000
      ATOT=TOTBIT;BER=ERROR/ATOT
      TYPE 22,ERROR,TOTBIT,SIGMA,BER
      WRITE (TU,22)ERROR,TOTBIT,SIGMA,BER
22    FORMAT(5X,'NO OF ERRORS=',I6/5X,'TOTAL
      1 NO OF BITS=',I7/5X,'SIGMA=',E15.8/5X,'BER=',E15.8)
      CLOSE(UNIT=60)
      CLOSE(UNIT=TU)
      STOP;END
```

```
      INTEGER DATA(500),DDATA(501),DATA1(10000),SS(10001),
     1PN(10000),AGREE1,AGREE2,ERROR,TOTBIT,DISAG1,DISAG2
     1,DIFF1,DIFF2,PN1(10000),SRC(11),TEMP(11)
      DIMENSION A(10001),GAUSS(10000)
      OPEN(UNIT=60,FILE='KOO.DAT')
      IU=61
      OPEN(UNIT=IU,FILE='SPREAD.FIL')
      READ(60,*)(SRC(J),J=1,11)
      READ(60,*)SIGMA
      READ(60,*)IL
      ERROR=0
      DO 21 L=1,IL
C..............................................................
C     DATA GENERATION
C..............................................................
      DO 2 I=1,5001
2     A(I)=RAN(DUM)
      DO 4 I=1,500
      DATA(I)=0
      IF(A(I).GE..5)DATA(I)=1
      K=I-1
      M=K*10
      DO 3 J=M+1,M+10
3     DATA1(J)=DATA(I)
4     CONTINUE
C..............................................................
C     PN SEQUENCE CREATION
C..............................................................
      DO 7 I=1,5000
      PN(I)=SRC(11)
      DO 5 J=1,11
5     TEMP(J)=SRC(J)
      TEMP(9)=TEMP(9)+TEMP(11);IF(TEMP(9).EQ.2)TEMP(9)=0
      TEMP(4)=TEMP(4)+TEMP(9);IF(TEMP(4).EQ.2)TEMP(4)=0
      TEMP(1)=TEMP(1)+TEMP(4);IF(TEMP(1).EQ.2)TEMP(1)=0
      DO 6 J=2,11
      K=13-J
6     SRC(K)=SRC(K-1);SRC(1)=TEMP(1)
      PN1(I)=PN(I)+1;IF(PN1(I).EQ.2)PN1(I)=0
7     CONTINUE
C..............................................................
C     SPREAD SPECTRUM CREATION
C..............................................................
      DO 8 I=1,5000
      [illegible]
```

```
      SS(I)=PN1(I);GO TO 9
8     SS(I)=PN(I)
9     CONTINUE
C.......................................................................
C     SPREAD SPECTRUM WITH ADDED NOISE
C.......................................................................
      PYE=3.14159265
      DO 12 I=1,5000;ZG1=A(I);ZG2=PYE*A(I+1)
      ZG1=(-2.)*ALOG(ZG1);ZG1=SQRT(ZG1);ZG2=COS(ZG2)
12    GAUSS(I)=ZG1*ZG2*SIGMA
      DO 112 I=1,5000
      IF(SS(I).EQ.1.AND.GAUSS(I).LT.-1.OR.SS(I).EQ.0.AND.
     1GAUSS(I).GT.1)SS(I)=SS(I)+1
      IF(SS(I).EQ.2)SS(I)=0
112   CONTINUE
C.......................................................................
C     CORRELATION OPERATION
C.......................................................................
      DO 20 I=1,500
      AGREE1=0;AGREE2=0
      DISAG1=0;DISAG2=0
      DIFF1=0;DIFF2=0
      K=I-1;M=K*10;DO 17 J=M+1,M+10
      IF(SS(J).EQ.PN(J))GOTO 16
      DISAG1=DISAG1+1;GO TO 17
16    AGREE1=AGREE1+1
17    CONTINUE
      DIFF1=AGREE1-DISAG1
      DO 18 J=M+1,M+10
      IF(SS(J).EQ.PN1(J))GOTO 19
      DISAG2=DISAG2+1;GO TO 18
19    AGREE2=AGREE2+1
18    CONTINUE
      DIFF2=AGREE2-DISAG2
      DDATA(I)=0
      IF(DIFF1.GT.DIFF2)DDATA(I)=1
20    CONTINUE
      DO 127 I=1,500
127   IF(DDATA(I).NE.DATA(I))ERROR=ERROR+1
21    CONTINUE
      TOTBIT=10*500
      ATOT=[illegible];BER=ERROR/ATOT
      [illegible],22)ERROR,SIGMA,TOTBIT,BER
      [illegible]22,[illegible],SIGMA,TOTBIT,BER
      [illegible]),'[illegible]ERRORS=',I6,5X,'SIGMA=',F6.4/5X,'TOTAL
```

```
1NO OF BITS='I7/5X,'BER='E15.8)
CLOSE(UNIT=60)
CLOSE(UNIT=10,FILE='SPREAD.FIL');STOP;END
```